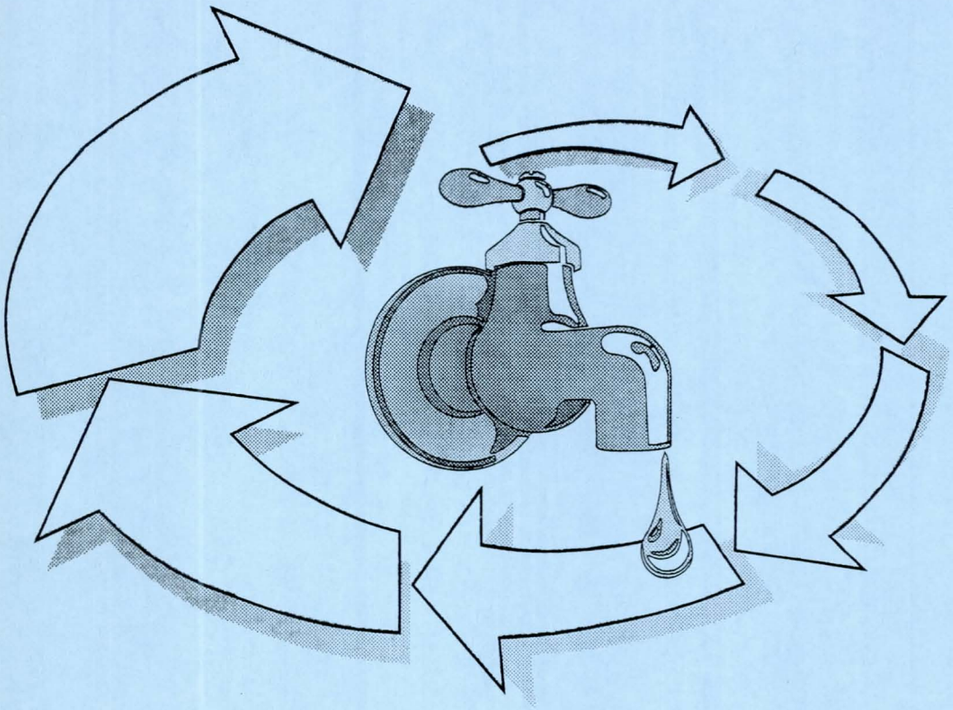
1992 WATER REUSE SYMPOSIUM



Embassy Suites
Tempe, Arizona
November 2, 1992

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AGENDA

SRP Water Reuse Symposium
November 2, 1992
Embassy Suites Hotel, Tempe

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Moderator:	**Mario Lluria, SRP**
8:00 - 8:30	**Registration/Continental Breakfast**
8:30 - 8:45	**Welcome -- Oren Thompson, SRP Associate General Manager of Customer, Marketing and Water Services**
8:45 - 9:20	**Water Reuse in Los Angles -- Bahman Sheikh, Director, Office of Water Reclamation**
9:20 - 9:55	**Pathogens and Health Effects -- Charles Gerba, University of Arizona**
9:55 - 10:10	**BREAK**
10:10 - 10:45	**Regulations and Guidelines -- Jim Crook, Camp Dresser & McKee Inc.**
10:45 - 11:20	**Proposed Revisions to Arizona's Water Reuse Regulations -- Steve Pawlowski, Arizona Department of Environmental Quality**
11:20 - 11:55	**Geopurification and Water Reuse -- Herman Bouwer, U.S. Water Conservation Lab.**
12:00 - 1:00	**LUNCH BUFFET**
Moderator:	**Bill Schaffer, ADEQ**
1:00 - 1:35	**Orange County Projects -- Martin Rigby, Orange County Water District**
1:35 - 2:10	**San Diego Projects -- Ken Thompson, Irvine Ranch Water District**
2:10 - 3:00	**Chemical and Biological Processes in the Vadose Zone --** **Field Studies: Gray Wilson, University of Arizona** **Laboratory Studies: Bob Arnold, University of Arizona**
3:00 - 3:15	**BREAK**
3:15 - 3:50	**Phoenix Zero Discharge Plans -- Oralynn Self (Greeley & Hansen) and Mike Gritzuk (City of Phoenix)**
3:50 - 4:50	**Panel: The Future of Water Reuse in Arizona -- Karl Kohlhoff (City of Mesa), Bruce Johnson (Tucson Water), Leonard Dueker (City of Scottsdale), Grant Anderson (City of Glendale), Herb Dishlip (DWR), Sue Lofgren (concerned citizen)**
4:50 - 5:00	**Closing Remarks/Adjourn**

WATER REUSE in LOS ANGELES

Bahman Sheikh
Director, Office of Water Reclamation

8:45 am -- 9:20 am

outline of presentation to

Water Reuse Symposium

Sponsored by the

Salt River Project

November 2, 1992

Water Reuse in Los Angeles

Bahman Sheikh, Ph.D., P.E.
Director, Office of Water Reclamation, City of Los Angeles

- Introduction

- Why is it important to maximize water recycling in Los Angeles, now?

  - Growth in demand
  - Threatened existing supplies
  - Future deficits
  - Desalination and other exotic supplies
  - Reclamation and conservation are the most reliable significant sources

- What is water reclamation, recycling, reuse?

  - Nature's way, the hydrologic cycle--use, collect, cleanse, store, transport, reuse
  - Worldwide practice, historic record
  - California experience--854 projects as of 1987 survey, expanding rapidly
  - Los Angeles County--185 water recycling projects, State's largest reuse volume
  - Direct potable reuse--California regulations being prepared by a committee of DWR and DoHS

- What is the existing experience with water recycling?

  - Universal acclaim where practiced over the past decades
  - Economical
  - Reliable and dependable supply
  - Excellent record on safety as shown by practical experience and numerous scientific studies

- What are the regulatory concerns?

  - Health departments unwilling to part with authority and to define new roles
  - Uneven enforcement by local health agencies
  - Resistance to change
  - Some regulators are reluctant to accept the safe record of water reuse--insist on tight regulations

- What are the institutional barriers?

  - Water industry is still largely devoted to development of additional imports
  - Old guard is unwilling to accept a significant role for water reuse
  - Inertia--go slow until *everyone* is on board
  - Fear of the "unknown"--it is still **news** to many in the water industry!

- What are the environmental implications of water reclamation?

  - Allows "adequate" water to be left in the areas from which we draw our supplies
  - Helps alleviate burden on receiving waters--e.g., Santa Monica Bay, San Francisco Bay and Delta...
  - Puts nutrients on the soil rather than in the water
  - Keeps urban environments green under drought conditions
  - Provides opportunities for urban streams restoration

- How much does it cost?

  - Competitive with **marginal** cost of water development (<$200 to >$750/AF)
  - Economics of water recycling are improving continuously
  - Irresponsible not to include water reuse in future water projects

- Who should/will pay the costs?

  - All citizens benefit when less water is withdrawn from the environment
  - Population in the region benefits when dependence on imports is reduced
  - Water rate payers benefit when reuse is developed to displace potable supplies
  - Therefore, subsidies from federal, state, and regional governments make sense
  - Rate-payer base for water reclamation is fair and equitable

- Why haven't we been more aggressive in water reuse?

  - "Cheap, abundant, unthreatened supplies", in the past. Some still perceive that!
  - Probably the last 100 years (of recorded history) were uncommonly "wet"
  - Dependence on imports to supplement shortfalls *ad infinitum*
  - "Lack of vision"

- What are future prospects for water recycling?

  - Aggressive plans are being developed to build the needed infrastructure
  - Expansion into residential non-potable uses with dual plumbing
  - Maximize groundwater recharge
  - Expanded use of reclaimed water to augment potable supply
  - Gray water will gain greater acceptance and more widespread use

- What is the role of the Office of Water Reclamation?

  - Policy analysis, Boards and Council recommendations
  - Monitoring opportunities to maximize water recycling
  - Public education
  - Closing the institutional gaps between departments
  - Legislative, regulatory reform to facilitate water reuse

PATHOGENS and HEALTH EFFECTS

Charles Gerba
University of Arizona

9:20 am -- 9:55 am

WATER REUSE REGULATIONS and GUIDELINES

Jim Crook
Camp Dresser & McKee Inc.

10:10 am -- 10:45 am

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QUALITY CRITERIA FOR RECLAIMED WATER

James Crook

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ABSTRACT

The applicability of reclaimed water for any particular use depends on its physical, chemical, and microbiological quality. The effects of physical and chemical parameters for nonpotable uses of reclaimed water are, for the most part, well understood and criteria have been established. Health-related microbiological limits are more difficult to quantify, as evidenced by widely varying standards and guidelines throughout the world. This paper presents existing reclaimed water quality limits for various uses, and compares the California Wastewater Reclamation Criteria, which are typical of health-related standards in industrialized countries, to WHO guidelines, which are directed principally at developing countries. The California regulations are considerably more restrictive than the WHO guidelines. Because of unknowns concerning the presence, identification, concentration, and health significance of many chemical constituents that may be in reclaimed water, quality criteria for potable reuse are not well developed and are not addressed in this paper.

KEY WORDS

Water reclamation, water reuse, quality criteria, reclamation criteria, health standards, guidelines, irrigation, microbiological limits, regulations.

INTRODUCTION

The planned reuse of municipal wastewater is not a new concept and has been practiced for many years throughout the world. With the concomitant increase in water demand as population grows, purposeful water reuse will play an increasing role in the planning and development of additional water supplies. Water reuse reduces the demand on freshwater supplies through "source substitution," that is, substituting reclaimed water for potable or other water for uses where the quality of the reclaimed water permits such substitution. In many cases, it also protects the quality of existing potable supplies by eliminating wastewater discharges into surface waters.

Water reclamation and reuse has emerged as a realistic option for new sources of water to help meet urban and agricultural needs. Table 1 lists the water reuse applications currently practiced in industrialized countries. Depending on local conditions, these water reuse applications may also be considered in developing countries.

Because domestic sewage is a hazardous substance known to contain many pathogenic agents, regulatory controls related to the use of reclaimed water are principally directed at public health protection. Regulatory agencies in industrialized countries

such as the U.S. typically impose restrictive treatment requirements, water quality limits, and use area controls to minimize the possibility of adverse health consequences. In contrast, the World Health Organization (WHO) has published guidelines, principally directed at developing countries, that are based on an evaluation of epidemiological studies of exposed populations and are significantly less restrictive in some respects. The experts who developed the WHO guidelines, which recommend stabilization pond systems as the preferred method of treatment, consider the high levels of treatment and water quality required in many industrialized countries to be unjustified and, in any case, not implementable in many developing countries for economic and technical reasons.

TABLE 1 Reclaimed Water Uses

Landscape Irrigation	Nonpotable Urban
Parks	Landscape Irrigation
Cemeteries	Fire Protection
Golf Courses	Toilet Flushing
Thoroughfare Rights-of-Way	Air Conditioning
School Grounds	Vehicle Washing
Greenbelts	Street Washing
Residential Lawns	
	Impoundments
Agricultural Irrigation	Ornamental
Fodder, Fibre, & Seed Crops	Recreational
Food Crops	
Nurseries	Environmental
Frost Protection	Streamflow Augmentation
Industrial	Marshes
Cooling	Wetlands
Boiler Feed	Fisheries
Stack Scrubbing	
Process Water	Miscellaneous
	Aquaculture
Groundwater Recharge	Snow-making
Recharge Potable Aquifer	Construction
Salt Water Intrusion Control	Dust Control
Subsidence Control	Livestock Watering

WATER QUALITY CONSIDERATIONS

The acceptability of reclaimed water for any particular use is dependent on the physical, chemical, and microbiological quality of the water. Factors that affect the quality of reclaimed water include source water quality, wastewater treatment, treatment reliability, and distribution system design and operation. Industrial source control programs can limit the input of chemical constituents that may adversely affect water quality. Assurance of treatment reliability is an obvious, yet sometimes overlooked, quality control measure. Distribution system design and operation is important to ensure that the reclaimed water is not degraded prior to use and not subject to misuse. Open storage may result in water quality degradation by microorganisms, algae, or particulate matter, and may cause objectionable odor or color in the reclaimed water.

Depending on the use, considerations for water quality criteria include the following.

- Public health protection. Reclaimed water must be safe for the intended use. Most reclaimed water criteria are principally directed at public health protection, and many address only microbiological concerns.

- Use requirements. Many industrial uses and some other applications have specific physical and chemical water quality requirements not related to health considerations. The physical, chemical, and microbiological quality may all limit the acceptability of reclaimed water.

- Irrigation effects. The effect of individual constituents or parameters on crops or other vegetation, soil, and groundwater must be considered.

- Environmental considerations. The natural flora and fauna in and around reclaimed water use areas and receiving waters should not be adversely affected by the reclaimed water.

- Aesthetics. For high level uses, e.g., urban irrigation and toilet flushing, the reclaimed water should not be different in appearance to potable water, i.e., clear, colorless, and odorless. For recreational impoundments, the reclaimed water should not promote algal growth.

- Public and/or user perception. The water must be perceived as being safe and acceptable for the intended use, and regulatory agencies must provide this assurance. This could result in the imposition of conservative quality limits by regulatory agencies.

- Political realities. Regulatory decisions are sometimes based on the political climate, perceived public policy, personal beliefs or biases, and cost.

For nonpotable uses of reclaimed water, the effects of many chemical constituents are relatively well understood and, therefore, quality limits can be readily determined. The effect of organic constituents in reclaimed water used for crop irrigation may warrant special attention, particularly if industrial wastes contribute a significant fraction to the wastewater. The health risks associated with microbiological agents are more difficult to assess. This is reflected in widely differing reclaimed water requirements throughout the world.

QUALITY CRITERIA

Existing Standards and Guidelines

The health problems associated with the reuse of raw or improperly treated wastewater are well documented (Feachem et al, 1980; Lund, 1980; Shuval et al, 1986). As a consequence, water reuse standards and guidelines are principally directed at public health protection and are generally based on the control of pathogenic organisms. Several countries with arid or semi-arid climates have developed criteria or guidelines intended to ensure that the reuse of wastewater does not present unreasonable health risks. There are no federal standards governing reuse in the U.S., although the U.S. Environmental Protection Agency published reuse guidelines in 1980 (EPA, 1980). The guidelines are currently being updated and expanded. Regulations that do exist in the U.S. have been developed at the state level.

California. The State of California has a long history of reuse and developed the first reuse regulations in 1918, which have been modified and expanded through the years. The state's current Wastewater Reclamation Criteria (State of California, 1978) were adopted in 1978 and have served as the basis for reuse standards in other states and countries. The reclamation criteria include water quality standards, treatment process requirements, operational requirements, and treatment reliability requirements. The treatment and quality criteria are shown in Table 2.

The coliform levels in Table 2 are not definitive threshold levels justified by rigorous documentation and evaluation of illness rates. At the time the regulations were developed, the California Department of Health Services concluded that epidemiological studies of the exposed population at water reuse sites would be of limited value, and that it was not possible to ascribe numerical risk estimates to

reclaimed water with any degree of confidence. Thus, the reclamation criteria were based on the capability of well designed and operated wastewater treatment plants to consistently attain specific effluent quality limits, experience at existing wastewater disposal and reuse operations, evaluation of pertinent research studies and health-related data, and the desire not to allow unreasonable risks due to the use of reclaimed water.

TABLE 2 California Treatment and Quality Criteria for Reuse[a]

Type of Use	Total Coliform Limits	Treatment Required
Fodder, Fiber, and Seed Crops Surface Irrigation of Orchards and Vineyards	—	Primary
Pasture for Milking Animals Landscape Impoundments Landscape Irrigation (Golf Courses, Cemeteries, etc.)	23/100 ml	Oxidation & Disinfection
Surface Irrigation of Food Crops[b] Restricted Recreational Impoundments	2.2/100 ml	Oxidation & Disinfection
Spray Irrigation of Food Crops[b] Landscape Irrigation (Parks, Playgrounds, etc.) Nonrestricted Recreational Impoundments	2.2/100 ml	Oxidation, Coagulation, Clarification, Filtration[c], & Disinfection

[a] From: State of California (1978).
[b] Exceptions may be made to the requirements for processed food crops.
[c] The turbidity of filtered effluent cannot exceed an average of 2 turbidity units during any 24-hour period.

As indicated in Table 2, the required degree of treatment and microbiological quality increase as the likelihood of human exposure to the reclaimed water increases. If intimate direct contact with the reclaimed water is expected, such as swimming, or indirect contact is likely, such as consuming produce spray-irrigated with reclaimed water, the regulations specify treatment and water quality requirements intended to produce an effluent that is essentially free of pathogens, including viruses. A fundamental decision was made that the standard to be applied was to be the absence of measurable levels of enterovirus, based on the assumptions that very low numbers of virus can initiate infection and wastewater treatment processes controlling enterovirus would produce reclaimed water free from any human pathogen and thus be safe for the intended uses (Crook, 1985).

Selection of the treatment chain specified in the Wastewater Reclamation Criteria to produce an essentially pathogen-free effluent, i.e., oxidation, chemical coagulation, clarification, filtration, and disinfection to a coliform level not exceeding 2.2/100 ml, was predicated on studies conducted several years ago to determine the virus removal capability of advanced wastewater treatment processes. More recent studies (County Sanitation Districts of Los Angeles County, 1977; Engineering-Science, 1987) indicated that equivalent virus removal can be achieved by direct filtration of high quality secondary effluent, using low coagulant and/or polymer dosages. This abbreviated treatment chain, in conjunction with specific design and operational

controls has been judged to be equivalent to the full treatment chain specified in the regulations. The required design and operational controls for direct filtration facilities include the following:

- Coagulant addition unless secondary effluent turbidity is less than 5 NTU
- Maximum filtration rate of 12 m/h (5 gpm/ft^2)
- Average filter effluent turbidity of 2 NTU or less
- High-energy rapid mix of chlorine
- Theoretical chlorine contact time of at least 2 hours with an actual modal contact time of at least 90 minutes
- Minimum chlorine residual of 5 mg/l after the required contact time
- Chlorine contact chamber length to width or depth ratio of at least 40:1
- 7-day median number of total coliform organisms in the effluent of 2.2/100 ml or less, not to exceed 23/100 ml in any sample

Other States. The California criteria are neither the most restrictive nor the least restrictive reuse standards in the U.S. In Florida, for example, secondary treatment, i.e., BOD and TSS not exceeding 20 mg/l, and disinfection to achieve an effluent fecal coliform level not exceeding 200 organisms/100 ml are required for the irrigation of areas with restricted public access and crops not intended for human consumption (State of Florida, 1989). For food crop irrigation, toilet flushing in buildings where the public does not have ready access to the plumbing system for repairs or modifications, and the irrigation of areas accessible to the public, including residential lawns, secondary treatment followed by filtration and disinfection is required with water quality limitations of 20 mg/l BOD, 5 mg/l TSS, and no detectable fecal coliforms 100/ml. Irrigation of edible crops that will not be peeled, skinned, cooked or thermally processed prior to consumption is prohibited.

Arizona is the only state in the U.S. with reuse standards that include limits for virus and parasites. For example, where reclaimed water is used to spray-irrigate food crops eaten raw, the Arizona regulations include the following water quality limits: 2.2 fecal coliform organisms/100 ml; 1 NTU turbidity; 1 enteric virus/40 l; and no detectable *Entamoeba hystolytica*, *Giardia lamblia*, and *Ascaris lumbriocoides* (State of Arizona, 1987).

World Health Organization Guidelines. In 1971, WHO sponsored a meeting of experts on the reuse of effluents and subsequently published a technical report (WHO, 1973) suggesting treatment processes to meet health criteria for irrigation, aquaculture, industrial uses, and municipal reuse for both nonpotable and potable reuse. Most of the recommendations have since been modified by WHO and need not be presented here. The health criteria for potable reuse included the following: no fecal coliform organisms in 100 ml; no virus particles in 1000 ml; no toxic effects on man; and other drinking water criteria. Although the experts suggested treatment processes that may be applicable to potable reuse, they recognized the uncertainties associated with the practice and concluded that drinking water should preferably come from a clean supply. Further, they concluded that conventional water standards were entirely inadequate as a means of determining the safety of reclaimed water for potable reuse and that research would be required to evaluate acute and long-term health effects of chemical constituents.

In 1985, a meeting of scientists and epidemiologists was held in Engelberg, Switzerland, to discuss the health risks associated with wastewater irrigation. The meeting, sponsored by WHO and other international organizations, reviewed health-related and other research made available since publication of the 1973 WHO guidelines and developed a revised approach to the nature of health risks associated with water reuse in agriculture and aquaculture. It was concluded that the health risks of irrigation with well treated wastewater were minimal and that then-current

bacterial standards were unjustifiably restrictive (IRCWD, 1985). The published summary of the meeting, known as the Engelberg Report includes tentative quality guidelines for reclaimed water used for irrigation. It was recommended that the number of intestinal nematodes not exceed 1 viable egg/litre for the irrigation of trees, industrial crops, fruit trees, and pasture. For the irrigation of edible crops, sport fields, and public parks, it was recommended that the number of intestinal nematodes not exceed 1 viable egg/litre and that the number of fecal coliform organisms not exceed 1000/100 ml.

TABLE 3 Recommended Microbiological Quality Guidelines for Wastewater use in Agriculture[a,b]

Category	Reuse Conditions	Exposed Group	Intestinal nematodes[c] (arithmetic mean no. of eggs per litre[d])	Fecal coliforms (geometric mean no. per 100 ml[d])	Wastewater treatment expected to achieve the required microbiological quality
A	Irrigation of crops likely to be eaten uncooked, sports fields, public parks[e]	Workers, consumers, public	≤1	≤1,000[d]	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
B	Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[f]	Workers	≤1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and fecal coliform removal
C	Localized irrigation of crops in Category B if exposure of workers and the public does not occur	None	Not Applicable	Not Applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

[a] From: WHO (1989).
[b] In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account, and the guidelines modified accordingly.
[c] *Ascaris* and *Trichuris* species and hookworm.
[d] During the irrigation period.
[e] A more stringent guideline (<200 fecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
[f] In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

A WHO Scientific Group on Health Aspects of Use of Treated Wastewater for Agriculture and Aquaculture met in Geneva in 1987, and their report was published by WHO in 1989 (WHO, 1989). These latest WHO guidelines reaffirm the recommendations of the Engelberg Report. The recommended microbiological quality guidelines for reclaimed water used for agricultural and urban irrigation are summarized in Table 3.

The guidelines in Table 3 are based on the conclusion that the main health risks in developing countries are associated with helminth diseases, and, therefore, a high degree of helminth removal is necessary for the safe use of wastewater in agriculture and aquaculture. While the guidelines do not specifically refer to all helminths of public health significance, the intestinal nematodes covered are intended to serve as indicator organisms for all of the large settleable pathogens. It is implied that all helminth eggs and protozoan cysts will be removed to the same extent. The guidelines indicate that other pathogens of interest apparently become nonviable in pond systems having long retention times. The helminth egg guidelines are intended to be a design standard, not a standard requiring routine testing of the effluent.

The Scientific Group concluded that no bacterial guideline is necessary in cases where the only exposed population is farm workers, due to a lack of evidence indicating a health risk to workers from bacteria. The recommended bacterial guideline of a geometric mean fecal coliform level of 1000/100 ml is based on the most recent epidemiological evidence and is considered to be technically feasible in developing countries. The Scientific Group indicated that the potential health risks associated with the use of reclaimed water for lawn and park irrigation may present greater potential health risks than those associated with the irrigation of vegetables eaten raw and, hence, recommended a fecal coliform limit of 200/100 ml for such urban irrigation.

The guidelines recognize that there are limited health effects data for reclaimed water used for aquaculture and do not recommend definitive bacteriological quality standards for this use. A tentative bacterial limit of a geometric mean number of fecal coliforms of 1000/100 ml is recommended in the guidelines, which is intended to ensure that invasion of fish muscle is prevented. The same fecal coliform standard is recommended for pond water in which aquatic vegetables (macrophytes) are grown. Since pathogens may be accumulated in the digestive tract and intraperitoneal fluid of fish and pose a risk through cross-contamination of fish flesh or other edible parts and subsequently to consumers if standards of hygiene in fish preparation are inadequate, a further recommended public health measure is to ensure that high standards of hygiene are maintained during fish handling and gutting. A total absence of viable trematode eggs, which is readily achieved by stabilization pond treatment, is recommended as the appropriate helminth quality guideline for aquacultural use of reclaimed water.

The 1989 WHO guidelines recognize waste stabilization ponds as the usual method of choice in warm climates wherever land is available at reasonable cost. The recommended microbiological guidelines can be reliably met with a series of ponds. Adequate helminth removal can be achieved with a total pond retention time of 8-10 days, but at least twice that time is usually required in hot climates to reduce bacterial levels to the guideline level. Tertiary treatment of conventional biologically treated secondary effluent may also be used to meet the recommended microbiological guidelines.

OTHER WATER QUALITY CRITERIA

Irrigation

Crop irrigation is the major use of reclaimed water in developing countries and is still a major use in many industrialized countries. Landscape irrigation of parks, golf courses, greenbelt areas, sports fields, residential lawns, etc. with reclaimed water is well established in industrialized countries, and the trend toward dual water distribution systems in urban areas will result in increased use of reclaimed water for all types of landscape irrigation.

Chemical constituents. The effects of many chemical constituents are well known and recommended limits have been established for inorganic constituents and other parameters. Potential irrigation problems can be classified according to salinity, permeability, specific ion toxicity, and miscellaneous effects. Guidelines which can be used to interpret irrigation water quality based on these classifications are presented in Table 4. The sodium adsorption ratio (SAR) numbers in this table should be adjusted for reclaimed water to include a more accurate estimate of calcium in the soil water following an irrigation (Westcot and Ayers, 1984). Recommended limits for some trace elements in irrigation water are given in Table 5. In most cases, these elements accumulate in plants and soils, and long-term buildup in soil could result in human and animal health hazards or cause phytoxicity.

TABLE 4 Guidelines for Interpretation of Irrigation Water Quality[a]

Potential Irrigation Problem	Units	None	Slight to Moderate	Severe
Salinity				
Electrical conductivity	mmho/cm	<0.7	0.7 - 3.0	>3.0
Total dissolved solids	mg/l	<450	450 - 2000	>2000
Permeability				
SAR[b] = 0 - 3 and conductivity		>0.7	0.7 - 0.2	<0.2
3 - 6		>1.2	1.2 - 0.3	<0.3
6 - 12		>1.9	1.9 - 0.5	<0.5
12 - 20		>2.9	2.9 - 1.3	<1.3
20 - 40		>5.0	5.0 - 2.9	<2.9
Specific Ion Toxicity				
From root absorption				
Sodium	SAR	<3	3 - 9	>9
Chloride	mg/l	<140	140 - 350	>350
Boron	mg/l	<0.7	0.7 - 3.0	>3.0
From foliar absorption				
Sodium	mg/l	<70	>70	
Chloride	mg/l	<100	>100	
Miscellaneous Effects				
Nitrogen (Total N)	mg/l	<5	5 - 30	>30
Bicarbonate (HCO_3)	mg/l	<90	90 - 500	>500
pH		Normal range	6.5 - 8.4	
Residual chlorine (Spray irrigation only)	mg/l	<1.0	1.0 - 5.0	>5.0

[a]Adapted from: Westcot and Ayers (1984).
[b]SAR = sodium adsorption ratio = $Na/\sqrt{(Ca + Mg)/2}$

Salinity is a particular concern in the use of reclaimed water for irrigation since wastewater generally has a higher salt content than freshwater. Where the TDS are high, the problem is aggravated by poor leaching of the soil and high evapotranspiration rates. Food crops are generally more sensitive to TDS than pasture or grasses.

If excessive quantities of soluble salts accumulate in the root zone, the osmotic pressure of the soil solution becomes excessively high and water becomes less available to the plants. As the amount of dissolved salts in irrigation water increases, crop yields decrease and eventually a point is reached where plant life cannot be sustained. The limiting concentrations depend on the plant, type of soil, climatological conditions, and amount of water applied. Because of the osmotic pressure effect of salts in water, more frequent irrigations are required than under normal nonsaline irrigation conditions.

TABLE 5 Recommended Limits for Trace Elements in Reclaimed Water used for Irrigation[a]

Constituent	Long-Term Use[b] (mg/l)	Short-Term Use[c] (mg/l)
Aluminium	5.0	20.0
Arsenic	0.10	2.0
Beryllium	0.10	0.5
Boron	0.75	2.0
Cadmium	0.01	0.05
Chromium	0.1	1.0
Cobalt	0.05	5.0
Copper	0.2	5.0
Fluoride	1.0	15.0
Iron	5.0	20.0
Lead	5.0	10.0
Lithium	2.5	2.5
Manganese	0.2	10.0
Molybdenum	0.01	0.05
Nickel	0.2	2.0
Selenium	0.02	0.02
Vanadium	0.1	1.0
Zinc	2.0	10.0

[a]Adapted from: National Academy of Sciences - National Academy of Engineering (1973).
[b]For water used continuously on all soils.
[c]For water used for a period of up to 20 years on fine-textured neutral or alkaline soils.

Many plants are sensitive to salts, which can stunt growth, cause leaf burn and leaf drop, and cause stem dieback. Some plants exhibit a specific toxicity to certain ions, such as chloride, boron, and sodium. Chlorides are present in nearly all waters. They are not necessary for plant growth and in high concentrations cause subnormal growth rates and burning of leaves. Foliar adsorption of chlorides in sprinkler irrigation systems may cause plant damage at fairly low concentrations. The sodium ion may also be toxic to certain shrubs. With overhead sprinkler irrigation and humidity less than 30 percent, sodium or chloride greater than 70 or 100 mg/l, respectively, have resulted in excessive leaf adsorption and crop damage to sensitive crops. Water containing a high concentration of sodium has an adverse effect upon the physical structure of clay soils by dispersing the soil colloids. This retards the movement of water and the leaching of salts and makes the soils difficult to work.

The fertilizer value of nutrients in wastewater is generally considered to be a benefit, but high nitrogen concentrations can be detrimental. Nitrogen concentrations below 5 mg/l are generally acceptable, but concentrations above 30 mg/l may present severe problems. High nitrogen concentrations can cause excessive vegetative growth at the expense of fruit production, may delay maturity, may result in reduced sugar or starch content of some food crops, and can adversely affect flavor and texture of food crops. On the other hand, fodder crops usually benefit from large amounts of nitrogen.

Clogging of irrigation systems can occur as a result of suspended solids, chemical precipitation, or biological growth. Deposition of sediment not only reduces the capacity of irrigation systems to carry and distribute water, but can also decrease reservoir storage capacity. Suspended solids may cause undue wear on irrigation pumps and pipes and plugging of nozzles or drip applicators, thus reducing irrigation efficiency. Generally, particulate matter that will pass a 200-mesh screen does not ordinarily cause plugging problems, even in drip systems (WPCF, 1989). Maintenance of a chlorine residual can control bacterial and algal growths in irrigation lines.

The extent to which organic chemicals in reclaimed water may be taken up by plants is not well documented. Plants are known to take up many pesticides through roots and translocate them within the plant. Unless industrial discharges add unusually high amounts of organic constituents to the wastewater, such constituents do not appear to be present at levels adequate to adversely affect either crops, vegetation, or consumers. However, definitive information is lacking in this area.

Free available chlorine in concentrations as low as 0.05 mg/l may cause leaf tip burn and damage some sensitive crops, although some crops and turf grasses are unaffected by much higher concentrations. Reclaimed water usually contains combined chlorine residuals, which have not been observed to cause plant damage at the levels normally present in treated wastewater.

Industrial Uses

Industrial uses of reclaimed water include cooling, processing, boiler feeding, washing, transporting material, and as an ingredient in a product. Quality requirements for many industrial uses of reclaimed water, e.g., process water, are dependent on the specific application, and it is not possible to generalize on the requirements. Approximately 75 percent of all industrial water use is for cooling, and cooling is the predominant reuse application.

Cooling water. The major problems associated with the use of reclaimed water as makeup cooling water are scale formation, corrosion, and biological fouling. Some of the parameters of concern and the problems they may cause are presented in Table 6. Where the possibility of exposure to aerosols or windblown spray exists, a high degree of disinfection may be required by regulatory agencies to ensure protection of the neighboring public as well as plant employees.

TABLE 6 Industrial Water Reuse Quality Concerns

Parameter	Concern
Residual organics	Bacterial regrowth Slime/scale formation Foaming
Ammonia	Corrosion in copper-based alloys Stimulates microbial growth Interference with disinfection
Phosphorus	Scale formation Stimulates microbial growth
Suspended solids	Deposition Clogging
Calcium, Magnesium, Iron, Silica	Scale formation

As a minimum, disinfected secondary effluent is required for cooling water, and tertiary treatment including filtration and high-level disinfection is preferable. Additional treatment by the industry is often required for recirculating cooling systems and often includes lime clarification or alum precipitation for nutrient removal. Ion exchange is effective in removing hardness from the water. Sulfuric acid may be added for pH and alkalinity control, polyphosphates for corrosion control, phosphonates or calcium phosphate for destabilization, polyacrylates for suspended solids dispersion, chlorine for biological control, and antifoaming agents for dispersion of foam caused by phosphates and some organic compounds.

A high blowdown rate will lower contaminant concentrations, but this results in a higher makeup water demand and greatly increases chemical additive costs. In practice, a five- to eight-fold concentration increase between makeup and blowdown water is common for cooling towers. Recommended water quality criteria for makeup water to recirculating systems with five cycles of concentration are presented in Table 7.

TABLE 7 Recommended Criteria for Cooling Makeup Water[a]

Parameter	Recommended Limit[b]
Silica (SiO_2)	50
Chloride (Cl)	500
Total dissolved solids	500
Hardness (CaCO3)	650
Alkalinity ($CaCO_3$)	350
Total suspended solids	100
Ammonia (NH_3)	1.0
Aluminium(Al)	0.1
Iron (Fe)	0.5
Manganese (Mn)	0.5
Calcium (Ca)	50
Magnesium (Mg)	30
Bicarbonate (HCO_3)	24
Sulfate (SO_4)	200
Phosphorus	1.0
pH, units	6.8 - 7.2
Total coliform, MPN/100 ml	2.2

[a]Adapted from WPCF (1989) and Asano et al (1988).
[b]Given in mg/l unless otherwise noted.

Quality requirements for once-through cooling water are considerably less stringent than those for cooling water makeup. Disinfected secondary or filtered secondary effluent is usually acceptable. The principal problems are slime growths in the cooling system and deposits from suspended matter in the water. Except in unusual situations, scaling and corrosion problems are not a concern in once-through systems (WPCF, 1989).

Boiler feed water. Reclaimed water used as boiler feed water requires extensive additional treatment and is usually not recommended. Calcium and magnesium salts are the principal contributors to scale formation and deposits in boilers, and feed water must be treated to remove hardness. Excessive alkalinity contributes to foaming and results in deposits in heater, reheater, and turbine units. Silica and aluminium form a hard scale on heat-exchanger surfaces, while high concentrations of potassium and sodium can cause excessive foaming in the boiler. Quality requirements are dependent on the operating pressure of the boiler, as indicated in Table 8.

Groundwater recharge. The purposes of groundwater recharge are to prevent saltwater intrusion into freshwater aquifers, to store the reclaimed water for future use, to reduce or prevent declines in groundwater levels, to control or prevent ground subsidence, or to augment nonpotable or potable aquifers. It can be accomplished by surface spreading, direct injection, or river bank or stream bed infiltration resulting from stream augmentation. River bank or stream bed infiltration is not common in the U.S., but it is extensively practiced in Europe, where the extracted water is often used as a source of drinking water after treatment by granular activated carbon filters, usually combined with sand filtration and ozonation.

Depending on the reclaimed water characteristics, type of soil, depth of aerobic zone and spreading area practices, soil percolation may provide additional treatment of the reclaimed water. High levels of microorganisms and some chemical constituents are removed via adsorption, decomposition, precipitation, ion exchange, oxidation,

reduction, and other chemical reactions in the upper levels of the soil. Some of these processes retard the rate at which specific chemicals move in the subsurface environment relative to the rate of movement of water. Soils have the capacity to retain large amounts of trace metal elements.

TABLE 8 Recommended Boiler Feed Quality Criteria[a,b]

Parameter	Low Pressure	High Pressure
Silica (SiO_2)	30	0.7
Aluminium(Al)	5	0.01
Iron (Fe)	1	0.05
Manganese (Mn)	0.3	0.01
Ammonia (NH_3)	0.1	0.1
Total dissolved solids	700	200
Copper (Cu)	0.5	0.05
Hardness ($CaCO_3$)	350	0.07
Alkalinity ($CaCO_3$)	350	40
Dissolved oxygen	2.5	0.007
Suspended solids	10	0.05

[a]Adapted from National Academy of Sciences-National Academy of Engineers (1973).
[b]Recommended limits given in mg/l.

Wastewater treatment and quality criteria for recharge water vary depending on the site-specific hydrogeologic conditions, type of recharge, and subsequent use of the extracted groundwater. Direct injection typically requires a high-quality effluent to prevent soil clogging by particulates upon injection, chemical precipitation, or biological growths.

Very restrictive water quality criteria, e.g., drinking water standards, may be required for indirect potable reuse via recharge. Drinking water standards do not adequately define the chemical quality of reclaimed water to be used for drinking. Due to the unknowns concerning the presence and health significance of many chemical constituents that may be present in reclaimed water, advanced wastewater treatment may be necessary for the recharge of potable aquifers by either spreading or injection.

SUMMARY

Reclaimed water quality criteria are based on specific use requirements, environmental and aesthetic considerations, and public health protection. The effects of many chemical constituents are well known for most nonpotable reuse applications and recommended limits have been established for these constituents, although some questions remain concerning the health significance of trace organics in reclaimed water used in agriculture and aquaculture. Health risks associated with microbiological pathogens are more difficult to quantify. Water quality criteria applied in industrialized and developing countries differ greatly due, in part, to differences in economic feasibility, available technology, general health levels of the populations, and social and political factors. The California reclamation criteria and similarly conservative standards provide a high degree of health protection deemed by health authorities to be necessary and appropriate for the conditions in those states or countries for which they were developed, where bacteria and viruses are considered to be the most important pathogens of concern. For developing countries, where parasitic infections are endemic, WHO guidelines recommend considerably less restrictive reclaimed water quality guidelines directed mainly toward helminth removal. The WHO guidelines can be readily achieved by low-cost wastewater treatment in stabilization pond systems.

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REGULATORY ISSUES ASSOCIATED WITH REUSE PRACTICES THROUGHOUT THE WORLD

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INTRODUCTION

Water reuse is an established practice in many countries throughout the world. Uses of reclaimed water are presented in Table 1. There are no federal regulations in the U.S. pertaining to water reuse; hence, the regulatory burden rests with the individual states. This has resulted in differing state standards, and many states do not have any standards for water reclamation and reuse. As a consequence, the need for national guidelines is receiving increasing consideration in the U.S.

For the purposes of this paper, regulatory issues are defined as disputes, conflicts, or disagreements related to regulatory agency standards or guidelines. Issues can develop from misconceptions, misinformation, personal beliefs and biases, conflicting objectives, conflicting technical data, an absence of definitive information to support (or oppose) regulatory decisions, and conflicting opinions of recognized experts. Some of the water reuse regulatory issues in the U.S. and elsewhere are as follows: appropriate treatment and quality requirements; selection of monitoring parameters and sampling frequency; allowable uses of reclaimed water; the value of epidemiological studies; applicability of risk analysis techniques; controls at the point of reuse; legal conflicts; economic feasibility; and institutional barriers. This paper will principally address the scientific and technical regulatory issues associated with water reuse.

An issue that has developed internationally in recent years is the appropriateness of guidelines for the use of wastewater for irrigation, published by the World Health Organization (WHO) in 1989[1]. The guidelines were initially directed at water reuse in developing countries but are now being touted by some experts as a "world standard". The WHO guidelines are considerably less restrictive than criteria adopted by industrialized countries.

NEED FOR NATIONAL GUIDELINES

Reuse projects can be difficult to implement due to any of the following reasons: inadequate planning; political, regulatory, institutional, and economic considerations; environmental impacts; and a lack of public support. Only a few states have comprehensive regulations or guidance documents addressing water reuse, and there is little consistency among the state regulations and guidelines that do exist. Regulations and guidelines differ in that regulations are enforceable by law, while guidelines are not legally enforceable and compliance is voluntary. Guidelines are sometimes included in regulations by reference and thus become enforceable requirements.

The U.S. Environmental Protection Agency (EPA) does not believe that national standards, e.g., treatment and quality requirements, for reuse are necessary at this time[2]. However, EPA has indicated an interest in developing scientifically and technically supportable guidelines that would include treatment and water quality

recommendations for various types of reuse. A 1988 national survey of utility managers, engineers, scientists, and other professionals highlighted the need for national guidelines. The survey identified the most important research areas in water reuse as reclaimed water quality standards, virology, and potable reuse regulations[3]. At the national level, development of water reuse guidelines appears to be more realistic and implementable than standards[4].

Advantages of national guidelines are that they would provide consistency, instill public confidence in reuse, encourage reuse, and require the least effort to establish scientifically and technically supportable guidelines that would be available for use in all 50 states. National guidelines would result in consistent guidelines for all reclaimed water users based on a sound technical rationale. The guidelines would help to eliminate regulatory decisions based on political climate, perceived public policy, and personal beliefs or biases. They would also help to eliminate independent, inconsistent decisions by regulators.

Operating agencies may more readily accept guidelines - and the public may more readily accept water reuse - if national experts were involved in their development. It is a common perception that the absence of state reuse guidelines or criteria indicates that reuse is prohibited. National guidelines may eliminate this real or perceived barrier. Also, one unified national effort to develop national guidelines would require less resources than those required to establish regulations and/or guidelines by the individual states.

While the development of national guidelines is a desirable goal, there are potential adverse effects. National guidelines may not be sensitive to local or regional conditions. It may be difficult to reconcile differences between national guidelines and existing state standards, policies, or guidelines. States may prefer to establish their own regulations or guidelines based on local situations and compatibility with existing regulations or laws. Finally, there may be a fear that federal guidelines would be the first step toward federal regulations.

EPA has recognized that guidelines will encourage reuse in areas where it is not now allowed or practiced and may eliminate some of the inconsistencies that characterize current regulations. It is EPA's view that comprehensive guidelines, coupled with flexible state regulations, will foster increased consideration and implementation of reuse projects[1]. In response to the need for guidelines, EPA and the U.S. Agency for International Development are cosponsoring development of state-of-the-art water reuse guidelines, scheduled for completion in 1992. The objective of the guidelines is to provide a comprehensive guidance manual to evaluate reuse and facilitate the orderly planning, design, and implementation of reclaimed water projects. The guidelines will include recommended reclaimed water criteria. For parameters where there is no concensus on specific limits, ranges of limits will be provided.

TREATMENT AND WATER QUALITY

Key factors in the establishment of water reclamation and reuse criteria include public health protection, public policy, past reuse experience, and economic feasibility. The adverse health consequences associated with the reuse of raw or improperly treated wastewater are well-documented[5,6,7]. As a consequence, water reuse standards and guidelines are principally directed at public health protection and generally are based on the control of pathogenic organisms. Many of

the regulatory issues are directly or indirectly related to health concerns.

Water-short states such as Arizona, California, Florida, and Texas have comprehensive regulations which prescribe requirements according to the end use of the reclaimed water[8,9,10,11]. Other states have regulations or guidelines which focus on land treatment or land application of wastewater rather than the beneficial reuse of reclaimed water, even though it may be used for irrigation of agricultural or landscape areas. The standards in states having the most reuse experience tend to be conservative, as are criteria in several other technologically-advanced countries where reuse is prevalent, e.g., Israel[12], Japan[13], and South Africa[14]. As an example, Table 2 provides a comparison of treatment and quality requirements for urban irrigation with reclaimed water for some of the states and countries that have developed criteria.

There are a number of specific issues related to water reuse regulations. Controversial topics associated with nonpotable reuse in the U.S. and elsewhere include the following:

- Inclusion of treatment unit process requirements in regulations in lieu of relying solely on reclaimed water quality requirements.
- Determination of the "best" indicator organism.
- Selection of reclaimed water quality parameters to be monitored, parameter limits, sampling frequency, and monitoring compliance point.
- The health hazards associated with aerosols or windblown spray from spray irrigation sites and industrial cooling towers.
- The value of epidemiological investigations.
- The use of risk assessment models to determine health risk and as a tool to determine appropriate water quality requirements.
- The acceptability of direct potable reuse.

A rigorous evaluation of these issues is beyond the scope of this paper. However, some of the opposing viewpoints related to these issues are presented below.

Treatment Requirements

Arguments in favor of including treatment process requirements in regulations include the following:

- Treatment reliability is enhanced.
- Use of water quality criteria alone, particularly those involving surrogate parameters, do not adequately characterize reclaimed water quality.
- A combination of treatment and quality requirements known to produce reclaimed water of acceptable quality obviate the need to monitor the finished water for certain constituents, e.g., some health-significant chemical constituents or

pathogenic microorganisms such as viruses. As an example, for uses where the California Department of Health Services (DOHS) has determined that reclaimed water should be essentially free of pathogenic organisms, DOHS specifies treatment processes (oxidation, filtration, and disinfection), operational requirements (filtration rates, chlorine contact time, etc.), and water quality parameters (turbidity and coliform organisms) that, in combination, have the capability to produce water of the desired quality[15].

- Expensive, time-consuming, and in some cases, questionable monitoring for pathogenic organisms, including viruses, is eliminated without compromising health protection.

Arguments against the inclusion of treatment process requirements in regulations include the following:

- Treatment process requirements may result in economic infeasibility.
- Treatment process requirements would stifle the development and implementation of innovative treatment techniques.
- The use of indicator organisms is adequate to characterize reclaimed water.
- The need to provide high levels of treatment such as filtration is not warranted based on available data and existing reuse experiences.
- The selection of treatment processes to meet established water quality limits should be left to the project proponents.

Indicator Organisms

In the U.S. and other industrialized countries, either total or fecal coliform organisms are the preferred indicator organisms for reclaimed water. The total coliform analysis includes enumeration of organisms of both fecal and nonfecal origin, while the fecal coliform analysis is specific for coliform organisms of fecal origin. Therefore, fecal coliforms are better indicators of fecal contamination than total coliforms. Other indicator organisms, e.g., enterococci and bacteriophages, have been proposed but for various reasons are not recommended or required in any existing reuse regulations or guidelines.

Regulatory decisions regarding the selection of which coliform organism to use are somewhat subjective. Where low levels of coliform organisms are required to indicate the absence of pathogenic bacteria, there is no consensus among microbiologists that the total coliform analysis is superior to the fecal coliform analysis. The use of total coliforms provides an added safety factor that appeals to regulatory agencies that adhere to a conservative approach to water reuse.

Water Quality Monitoring

Water quality monitoring is often the most prominent issue during development of reuse standards or guidelines. Decisions involving monitoring include: selection of water quality parameters; numerical limits; sampling frequency; and the monitoring compliance point. It would be impractical to monitor reclaimed water for all of the toxic

chemicals and pathogenic organisms of concern and surrogate parameters are universally accepted. In addition to the previously described issue of whether to use total or fecal coliform organisms, important issues include the need to monitor viruses and the appropriate parameter for measurement of particulates. It is noteworthy that Arizona is the only state that has a virus standard[8]. Advocates of virus monitoring provide the following arguments:

- Low levels of viruses can initiate infection or disease, and raw sewage is known to contain a myriad of pathogenic viruses.
- Some viruses are more resistant to disinfection than coliform organisms, and there is little correlation between coliform level and virus concentration.
- Relying on treatment and coliform monitoring is inadequate to insure that viruses are reduced to acceptable levels.
- Virus monitoring can be a valuable tool in gaining public acceptance of reuse.

Arguments against the imposition of required virus monitoring include the following:

- A significant body of information exists indicating that viruses are removed or inactivated to low or immeasurable levels via appropriate wastewater treatment, including filtration and disinfection.[16,17,18]
- The identification and enumeration of viruses in wastewater are hampered by relatively low virus recovery rates, the complexity and high cost of laboratory procedures, and the limited number of facilities having the personnel and equipment necessary to perform the analyses.
- The laboratory culturing procedure to determine the presence or absence of viruses in a water sample takes about 14 days, and another 14 days are required to identify the viruses.
- There is no consensus among virus experts regarding the health significance of low levels of viruses in reclaimed water.
- There have been no documented cases of viral disease resulting from the reuse of wastewater at any of the wastewater reuse operations in the U.S.

The removal of suspended matter is related to the virus issue. It is known that many pathogens are particulate-associated and that particulate matter can shield both bacteria and viruses from disinfectants. Also, organic matter consumes chlorine, thus making less of the disinfectant available for disinfection. There is general agreement that particulate matter should be reduced to low levels, e.g., 2 NTU or 5 mg/l TSS, prior to disinfection to insure reliable destruction of microorganisms.

Suspended solids measurements are typically performed daily on a composite sample, and only reflect an average value. A common argument in support of the use of suspended solids analysis is that the required sampling frequency for most other important parameters is daily, and, therefore, more frequent monitoring for particulate matter

is unjustified. It is clear that continuously monitored turbidity is superior to daily suspended solids measurements as an aid to treatment operation. Reliable instrumentation is available for continuous online measurement of turbidity, and as a result turbidity has found wide application as a water quality parameter at water reclamation facilities. A low turbidity value by itself does not indicate that reclaimed water is devoid of microorganisms. As such, turbidity is not used as an indicator of microbiological quality but rather as a quality criterion for wastewater prior to disinfection.

Reclaimed water quality standards, particularly microbiological limits, vary considerably among U.S. states and among countries. Arguments for less restrictive standards are most often predicated upon a lack of documented health hazards rather than upon any certainty that hazards are small or nonexistent. In the absence of a common interpretation of scientific and technical data, selection of water quality limits will continue to be somewhat subjective and inconsistent among the states.

The location of the monitoring point for regulatory compliance has been an issue in some states. One viewpoint is that the reclaimed water should meet all water quality requirements at the point of use. Arguments in favor of this position generally center around the possible regrowth of microorganisms between the treatment plant and the point of reuse and algal growth in storage ponds that may create aesthetic problems and clog sprinkler heads. However, for most uses of reclaimed water, the restrictive coliform requirements insure that pathogenic bacteria are destroyed during disinfection and any bacterial regrowth would only be that of nonpathogenic coliform organisms.

Many regulatory agencies subscribe to the rationale that any degradation that may occur during storage and distribution would be no different than that which would occur with the use of other water. This is not meant to imply that subsequent water quality control should be ignored. For example, maintenance of a chlorine residual will reduce slime growths in distribution systems, help eliminate musty odors, and provide an added disinfection safety factor.

Aerosols

Viruses and most pathogenic bacteria are in the respirable size range; hence, a possible direct means of human infection by aerosols is by inhalation. Infection of disease can be contracted indirectly by deposited aerosols or windblown spray on surfaces such as food, vegetation, and clothes. Aerosols generated from the spray irrigation of undisinfected wastewater have been implicated in disease transmission[6].

There have not been documented outbreaks resulting from the spray irrigation of disinfected reclaimed water, and studies indicate that the health risk associated with aerosols from disinfected reclaimed water is low[19]. However, until more sensitive and definitive studies are conducted to fully evaluate the ability of aerosols to cause disease, the general practice is to limit exposure to aerosols through design or operational controls.

Epidemiological Studies

Epidemiological investigations directed at wastewater- contaminated drinking water supplies, use of raw or minimally treated wastewater for food crop irrigation, health effects to farmers who routinely

contact poorly treated wastewater used for irrigation, and the health effects of aerosols or windblown spray emanating from spray irrigation sites using undisinfected wastewater have all provided evidence of disease transmission from such practices[6,7]. The situation is different where wastewater is treated to relatively high levels and includes disinfection.

Most health experts agree that epidemiological studies of the exposed population at water reuse sites would be of limited value because of the mobility of the population, the small size of the study population, the difficulty in determining the actual level of exposure of each individual, the low illness rate - if any - resulting from the reuse practice, insufficient sensitivity of current epidemiological techniques to detect low-level disease transmission, and other confounding factors. It is particularly difficult to detect low-level transmission of viral disease, because many enteric viruses cause such a broad spectrum of disease syndromes that scattered cases of acute illness would probably be too varied in symptomology to be attributed to a single etiological agent. Thus, while the few epidemiological studies that have been conducted on reuse operations in the U.S. have not indicated adverse health responses and lead some to believe that stringent water quality standards are not justified, most regulatory agencies have chosen not to use such studies as a basis for determining quality standards.

Risk Assessment

The use of risk assessment to determine adequate levels of health protection for nonpotable uses of reclaimed water is a relatively new concept that warrants further development. Several technical papers have been published in recent years advocating the use of risk analysis in assessing microbiological health risks[20,21,22]. Some microbiologists assert that the state-of-the-art of risk analysis models for microorganisms is developed to the point where definitive health assessments are now possible. Others contend that risk assessment of microbiological disease hazards would of necessity include so many estimates and assumptions that the analysis would be of little practical value to regulatory agencies. The use of risk analysis as a tool in assessing relative health risks associated with the presence of human pathogens in reclaimed water is likely to receive increasing attention in the future.

Potable Reuse

Indirect potable reuse, principally via groundwater recharge, is an accepted practice in many states in the U.S. and in other countries arould the world. Planned direct potable reuse, on the other hand, is not currently being practiced anywhere. The only direct potable reuse facility in the world is at Windhoek, Namibia, and it is not currently in operation. Direct potable reuse is an extremely controversial and emotional issue. The arguments for and against direct potable reuse are well known and need not be repeated in detail here.

Briefly stated, advocates of potable reuse contend that wastewater can be treated to almost any desirable level of purity and that studies have demonstrated that currently available technology can produce reclaimed water of potable quality. Opponents of potable reuse contend that questions remain, particularly regarding the presence and concentration of organic constituents in reclaimed water and their related health effects. Opponents also cite the need for absolute reliability to insure health protection.

There is a philosophical element to this issue. It has always been the philosophy of public health officials that public water supplies should be derived from the most protected source, and lower quality source waters should be used for less demanding purposes. Most health officials prefer to defer direct potable reuse until there is a demonstrated need for additional water and alternative sources of supply are not available. Health officials support research to fully evaluate possible ramifications before direct potable reuse is implemented.

WORLD HEALTH ORGANIZATION GUIDELINES

A WHO Scientific Group on Health Aspects of Use of Treated Wastewater for Agriculture and Aquaculture met in Geneva in 1987, and their report has been published by WHO as Health guidelines for the use of wastewater in agriculture and aquaculture[1]. The microbiological quality guidelines recommended by the WHO Scientific Group for reclaimed water used for agricultural and landscape irrigation are summarized in Table 3. The guidelines in Table 3 are based on the conclusion that the main health risks in developing countries are associated with helminth diseases, and therefore, a high degree of helminth removal is necessary for the safe use of wastewater in agriculture. The helminth egg recommended limits are intended to be a design standard, not a standard requiring routine testing of the effluent. The guidelines recognize waste stabilization ponds as the method of choice in warm climates where land is available at reasonable cost.

The Scientific Group that developed the guidelines criticized the California Wastewater Reclamation Criteria, which have served as the basis for reuse regulations in both industrialized and developing countries, as being too stringent, not based on epidemiological evidence, unattainable, and not appropriate for developing countries. The California standards, which are summarized in Table 4, are intended to "establish acceptable levels of constituents of reclaimed water and to prescribe means for assurance of reliability in the production of reclaimed water to ensure that the use of reclaimed water does not impose undue risks to health"[9]. They are not intended to - nor do they - provide for zero risk. They are not based on epidemiological studies for reasons previously mentioned in this paper.

The California standards are based principally on the control of bacteria and viruses, which are the major wastewater associated pathogens of concern in the U.S. They were developed for use in that state, where they have been shown to be readily attainable at more than 200 reclamation facilities. It is not surprising that the California regulations (and those of other states and industrialized countries) are not achievable in developing countries due to economic and technological differences between developed and developing countries.

The WHO guidelines have been criticized as being seriously flawed and severely lowering the international 'common denominator' of the necessary public health quality requirements for irrigation with reclaimed water[23]. The intentions of international organizations such as the World Bank and United Nations Development Programme, who sponsored early work in this area, were to introduce at least some treatment of the wastewater prior to crop irrigation in developing countries. This concept is understandable and commendable, and the WHO guidelines satisfy that intent. The WHO guidelines are appropriate as an interim measure in developing countries until there

is an ability to produce higher quality reclaimed water. It is unlikely that the guidelines will replace existing reclamation criteria in developed countries.

CONCLUSIONS

Many of the water reuse regulatory issues around the world are related to health concerns. The lack of definitive information regarding microbiological health risks has resulted in considerable variation among water reuse guidelines and regulations in the U.S. and elsewhere. In the absence of a common interpretation of scientific and technical data, selection of reclaimed water treatment process requirements, water quality limits, and operational and use area controls will continue to be somewhat subjective and inconsistent. The need for national reuse guidelines is receiving increasing attention in the U.S., and it is likely that EPA will pursue the development of such guidelines. Recently published WHO guidelines are principally directed at developing countries and, in general, are less restrictive than those of developed countries. It is unlikely that they will replace existing criteria in developed countries.

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Table 1. RECLAIMED WATER USES

Landscape Irrigation	Nonpotable Urban
Parks	Landscape Irrigation
Cemeteries	Fire Protection
Golf Courses	Toilet Flushing
Thoroughfare Rights-of-Way	Air Conditioning
School Grounds	Vehicle Washing
Greenbelts	Street Washing
Residential Lawns	
	Impoundments
Agricultural Irrigation	Ornamental
Fodder, Fiber & Seed Crops	Recreational
Food Crops	
Nurseries	Environmental
Frost Protection	Streamflow
	Augmentation
Industrial	Marshes
Cooling	Wetlands
Boiler Feed	Fisheries
Stack Scrubbing	
Process Water	Miscellaneous
	Aquaculture
Groundwater Recharge	Snow-making
Recharge Potable Aquifer	Construction
Salt Water Intrusion Control	Dust Control
Subsidence Control	Livestock Watering

Table 2. STANDARDS FOR URBAN IRRIGATION WITH RECLAIMED WATER

State	Quality Limits	Treatment Required
Arizona	25 fecal coli/100 ml 5 NTU 125 virus/40 l No detectable *Ascaris lumbricoides*	Not specified
California	2.2 total coli/100 ml 2 NTU	Oxidation, filtration, and disinfection
Florida	No detectable fecal coli/100 ml 20 mg/l BOD 5 mg/l TSS 1 mg/l Cl_2 residual (min.)	Secondary, filtration, and disinfection
Texas	75 fecal coli/100 ml 3 NTU 5 mg/l BOD	Not specified
Israel	2.2 total coli/100 ml 15 mg/l BOD 15 mg/l TSS 0.5 mg/l Cl_2 residual (min.)	Oxidation, filtration, and disinfection
Japan	No detectable E. coli/100 ml 0.4 mg/l Cl_2 residual (min.) pH 5.8-8.6	Not specified
South Africa	General drinking water standards	Advanced Treatment

Table 3. RECOMMENDED MICROBIOLOGICAL QUALITY GUIDELINES FOR WASTEWATER USE IN AGRICUTLURE[a,b]

Reuse Conditions	Exposed Group	Intestinal nematodes[c] (arithmetic mean no. of eggs per liter[d])	Fecal coliforms (geometric mean no. per 100 ml[d])	Wastewater treatment expected to achieve the required microbiological quality
Category A Irrigation of crops likely to be eaten uncooked, sports fields, public parks[e]	Workers, consumers, public	≤1	≤1,000[e]	A series of stabilization ponds designed to achieve the microbiological quality indicated, or equivalent treatment
Category B Irrigation of cereal crops, industrial crops, fodder crops, pasture and trees[f]	Workers	≤1	No standard recommended	Retention in stabilization ponds for 8-10 days or equivalent helminth and fecal coliform removal
Category C Localized irrigation of crops in Category B if exposure of workers and the public does not occur	None	Not Applicable	Not Applicable	Pretreatment as required by the irrigation technology, but not less than primary sedimentation

[a] From: World Health Organization[1].
[b] In specific cases, local epidemiological, sociocultural and environmental factors should be taken into account, and the guidelines modified accordingly.
[c] *Ascaris* and *Trichuris* species and hookworm.
[d] During the irrigation period.
[e] A more stringent guideline (<200 fecal coliforms per 100 ml) is appropriate for public lawns, such as hotel lawns, with which the public may come into direct contact.
[f] In the case of fruit trees, irrigation should cease two weeks before fruit is picked, and no fruit should be picked off the ground. Sprinkler irrigation should not be used.

Table 4. CALIFORNIA TREATMENT AND QUALITY CRITERIA FOR REUSE[a]

Type of Use	Total Coliform Limits	Treatment Required
Fodder, Fiber, and Seed Crops Surface Irrigation of Orchards and Vineyards	—	Primary
Pasture for Milking Animals Landscape Impoundments Landscape Irrigation (Golf Courses, Cemeteries, etc.)	23/100 ml	Oxidation & Disinfection
Surface Irrigation of Food Crops[b] Restricted Recreational Impoundments	2.2/100 ml	Oxidation & Disinfection
Spray Irrigation of Food Crops[b] Landscape Irrigation (Parks, Playgrounds, etc.) Nonrestricted Recreational Impoundments	2.2/100 ml	Oxidation, Coagulation, Clarification, Filtration[c], & Disinfection

[a] From: State of California[9]
[b] Exceptions may be made to the requirements for processed food crops.
[c] The turbidity of filtered effluent cannot exceed an average of 2 turbidity units during any 24-hour period.

WATER RECLAMATION

JAMES CROOK
Camp Dresser & McKee Inc.

I. Historical Perspective
II. Uses of Reclaimed Water
III. Health Assessment
IV. Removal of Wastewater Constituents
V. Reuse Applications
VI. Reuse Standards and Guidelines
VII. Public Policy

ENCYCLOPEDIA OF PHYSICAL SCIENCE
AND TECHNOLOGY, 1990 YEARBOOK

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GLOSSARY

Advanced wastewater treatment: Physical, chemical, or biological treatment process used to accomplish a degree of treatment greater than that achieved by secondary treatment; also called tertiary treatment.

Carcinogen: Cancer-causing substance.

Coliform organisms: Group of bacteria predominantly inhabiting the intestinal tract of warm-blooded animals; includes all aerobic and facultative anaerobic, gram-negative, nonspore-forming, rod-shaped bacteria that ferment lactose and produce gas.

Direct potable reuse: Discharge of reclaimed water directly into a potable water system.

Disinfection: Destruction of pathogenic organisms by chemical, physical, or biological means.

Dual water distribution system: Facilities that distribute two grades of water to the same service area, one potable and the other nonpotable, for example, reclaimed water.

Enteric: Pertaining to the small intestine.

Fecal coliform organisms: Aerobic and facultative, gram-negative, nonspore-forming, rod-shaped bacteria capable of growth at 44.5°C and associated with fecal matter of warm-blooded animals.

Gastrointestinal: Refers to the stomach and intestines.

Helminth: Parasitic worm.

Indirect potable reuse: Discharge of treated wastewater to surface or underground waters from which water is drawn, provided additional treatment, and distributed through a potable water distribution system.

Infection: Entry and development or multiplication of an infectious agent in the body of humans or animals.

Mutagen: Substance that alters the genetic structure of a cell, especially reproductive cells.

Nonpotable water: Water not acceptable for potable uses.

Parasite: Organism that thrives on other living organisms.

Pathogen: Organism capable of causing disease in a susceptible host.

Potable water: Water of excellent quality that conforms to the drinking water quality requirements of state and federal regulatory agencies and is considered satisfactory for domestic consumption.

Primary treatment: Wastewater treatment processes usually consisting of clarification with or without chemical treatment to accomplish solid–liquid separation.

Protozoa: Small, one-celled animals including amoebae, ciliates, and flagellates.

Reclaimed water: Water that, as a result of treatment of domestic wastewater, is suitable for a beneficial use.

Reuse: Application of reclaimed water for a beneficial purpose.

Secondary treatment: Generally, a level of treatment that produces removal efficiencies for biochemical oxygen demand (BOD) and suspended solids (SS) of 85% or greater; commonly consists of clarification followed by a biological process, with separate sludge collection and handling.

Teratogen: Substance causing birth defects.

Tertiary treatment: Treatment of wastewater beyond the secondary or biological stage; also called advanced wastewater treatment. For reclamation, it generally includes filtration and disinfection.

Turbidity: Condition in water caused by the presence of suspended matter, resulting in the scattering and absorption of light; also, an analytical quantity reported in nephelometric turbidity units determined by measurements of light scattering.

Waterborne disease: Disease caused by organisms or toxic substances carried by water.

The reuse of wastewater for various purposes has been practiced for many years in several parts of the world. As the demand for water increases, wastewater reuse will play an ever-increasing role in the planning and development of additional water supplies. With the concomitant increase in water demand as population grows, the incentive to reclaim wastewater will become stronger. Even in water-rich regions, there may be local shortages because of urbanization and industry. Water reuse not only reduces the demand on fresh water supplies, but, in many cases, it also protects the quality of existing potable supplies.

Reuse involves considerations of public health, water conservation, water pollution control, and water management. Implementation of wastewater reuse schemes depend on several factors, including economic considerations, potential uses for the reclaimed water, severity of wastewater discharge requirements, environmental concerns, and public policy wherein the desire to conserve rather than develop available water resources may override other considerations. Nonpotable water reuse provides a

viable option for increasing water resources and is increasingly being considered along with other more conventional options.

I. Historical Perspective

Water has always been used and reused by humans. The natural water cycle, evaporation and precipitation, is one of reuse. Water is withdrawn from surface streams and wastes are discharged into these same streams, which in turn become the water supplies for downstream users. In the past, dilution and natural purification were usually sufficient to allow such a system to be satisfactory, but in recent years, population and industrial growth have made it evident that wastewater must be adequately treated before discharge in order to maintain the quality of the stream. [*See* Encyclopedia article WATER RESOURCE SYSTEMS.]

The earliest known planned reclaimed water system was built in Rome almost 2000 years ago, where an aqueduct carried water that was so unwholesome it was not used for potable purposes. The water was used for nonpotable purposes in order to preserve the higher quality source for drinking. This concern for water quality has transcended subsequent generations. In an effort to improve water quality over a century ago, Great Britain passed the Rivers Pollution Prevention Act of 1876. This act required that treatment of wastes discharged into British waterways be "the best or only practical and available means under the circumstances." Nearly a century later in the United States, Congress enacted the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500), which established "the best practical waste treatment technology" as a minimum requirement for publicly owned treatment works discharging wastewaters into navigable waters.

The first documented municipal wastewater agricultural reuse system was initiated in Germany in the 16th century. In the middle of the 19th century, concerns about water pollution associated with the growth of cities and industry resulted in the beginnings of sewage farming in Great Britain. By the late 19th century, irrigation of crops with municipal sewage was an established practice on farms near major cities in England, Australia, Germany, and France. Shortly thereafter, sewage farms became established in the United States, where they served as a popular land disposal method.

In the early part of this century, irrigation with raw sewage for the primary purpose of sewage disposal fell into general disfavor. Solids and grease in the raw sewage tended to create nuisances, sewage flows had increased, and the tendency to overload the soil led to anaerobic soil conditions. When sewage treatment capable of stabilizing sewage sufficiently to prevent gross odors was required, communities usually found it less expensive to provide longer outfalls, partial treatment, and disposal of effluent by dilution in fresh- or saltwater so that sewage farming was no longer attractive.

Some of the more significant firsts in water reuse in the United States are listed here.

1926 A dual water system at Grand Canyon National Park used reclaimed water for toilet flushing, landscape irrigation, and cooling water.

1929 The city of Pomona, California, initiated a project utilizing reclaimed wastewater for landscape and garden irrigation.

1931 A lawn and shrubbery irrigation project began at San Diego State Teachers College in California.

1932 Large-scale landscape irrigation began at Golden Gate Park in San Francisco, California. Reclaimed water was also used as a source of supply to ornamental lakes at the park.

1942 The use of chlorinated secondary effluent for cooling at the Bethlehem Steel Corporation in Baltimore, Maryland, began.

1960 A dual water system was initiated in Colorado Springs, Colorado, which now supplies reclaimed water for landscape irrigation for golf courses, parks, cemeteries, and freeways.

1962 Recharge of reclaimed water into groundwaters at Whittier Narrows, California, marked the first deliberate introduction of reclaimed water into sources of domestic water supply. A schematic of the 15-mgd (million gallons per day; 57,000 m^3/d) Whittier Narrows wastewater reclamation plant is shown in Fig. 1.

1976 Groundwater recharge of reclaimed wastewater by direct injection was initiated by the Orange County Water District in California. While the main purpose of the injection is to prevent saltwater intrusion, a high percentage of the injected reclaimed water recharges groundwater aquifers.

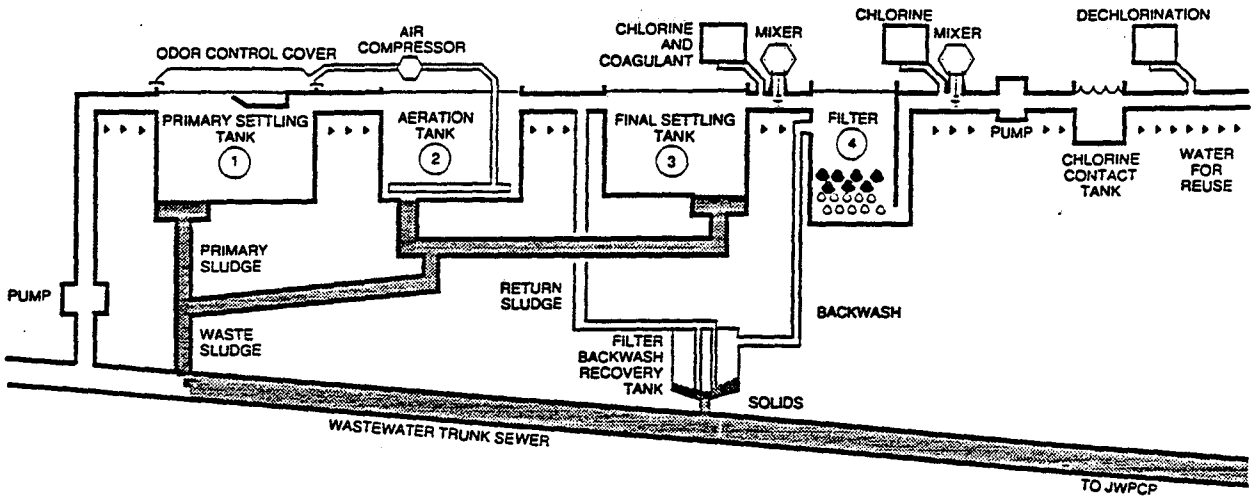

FIG. 1. Schematic of Whittier Narrows wastewater reclamation plant. JWPCP ≡ joint water pollution control plant.

1977 A major dual water system was instituted by the Irvine Ranch Water District in California, in which reclaimed water is supplied to irrigate farmland, residential areas, parks, golf courses, roadway median strips, and other open space. St. Petersburg, Florida, also began a dual water system in which reclaimed water is supplied for industrial use and irrigation purposes for golf courses, parks, and individual homes. This is the first and largest individual residence irrigation reuse system in the world.

Not all of these projects were developed out of a necessity to meet water shortages. Many were developed to take advantage of the wastewater as a resource that was available at a reasonable cost or as a lower cost means of disposal. As wastewater discharge requirements become increasingly more stringent, reuse is often an attractive alternative to discharge. The trend through the years has been toward uses involving increasing human contact with the reclaimed water and thus necessitating higher levels of treatment. [*See* Encyclopedia article WASTEWATER TREATMENT.]

II. Uses of Reclaimed Water

Approximately 50% of freshwater use in the United States is for agricultural irrigation, 40% is for industrial purposes, 6% is for domestic use, and the remaining 4% is for commercial and other uses. Domestic use accounts for 40% of the community water use in the United States and includes car washing, residential irrigation, toilet flushing, bathing, laundry, food preparation, and drinking. The nationwide average of water usage in urban potable water systems is 160 gal per capita per day (600 liters/capita/day). With feasible technology and under the appropriate conditions, reclaimed water may be used for virtually all nonpotable purposes for which water is utilized. The overriding consideration is that the quality of the water be appropriate for its use. Table I illustrates the various types of wastewater reuse either currently practiced or under consideration.

Detailed, up-to-date information on the number and type of wastewater reclamation projects on a national or international level is virtually impossible to obtain. In 1979, there were 536 documented reuse operations in the United States using approximately 680 mgd [2.6×10^6 cubic meters per day (m^3/d)] of reclaimed water. This figure has increased significantly since then. It has been estimated that by 1990 reuse of reclaimed water will exceed 1.5 billion gallons per day (bgd) (5.7×10^6 m^3/d). Table II indicates the type and number of reuse projects in California in 1984. During that year, approximately 220,000 acre-feet (270×10^6 m^3) of reclaimed water was used in California. Historically, the largest uses of reclaimed water do not require a high-quality effluent, for example, pasture irrigation, and are often perceived as a method for wastewater disposal. In recent years, a trend toward higher level uses, for example, urban landscape irrigation, industrial reuse, and groundwater recharge, is evident.

There are many reasons why water reuse projects are implemented, including the following.

1. *Opportunity:* Historically, most reuse operations were located in areas close to the existing treatment plants for uses not requiring additional treatment and where extensive transmission pipelines were unnecessary. Under such conditions, reuse is more opportunistic in nature than the result of a well-planned program to supplement or replace the use of

TABLE I. Reclaimed Water Uses

Landscape irrigation	Nonpotable urban
Parks	Fire protection
Cemeteries	Toilet flushing
Golf courses	Air conditioning
Thoroughfare rights-of-way	Washing machines
School grounds	Vehicle washing
Greenbelts	Street washing
Residential lawns	Impoundments
Agricultural irrigation	Ornamental
Fodder, fiber, and seed crops	Recreational
Food crops	Environmental
Nurseries	Stream low augmentation
Frost protection	Marshes
Industrial	Wetlands
Cooling	Fisheries
Boiler feed	Miscellaneous
Stack scrubbing	Aquaculture
Process water	Snowmaking
Groundwater recharge	Construction
Recharge potable aquifer	Dust control
Saltwater intrusion control	Livestock watering
Subsidence control	

TABLE II. Water Reuse in California in 1984

Uses	Number of installations
Irrigation of fodder, fiber, and seed crops	190
Landscape irrigation—golf courses and similar areas	85
Landscape irrigation—parks and similar areas	29
Orchard and vineyard irrigation	26
Food crop irrigation	10
Industrial uses	9
Restricted recreational impoundments	6
Landscape impoundments	6
Groundwater recharge	5
Nonrestricted recreational impoundments	1
Other	16
Total	383

potable water for nonpotable purposes. Such opportunistic reuse is dependent on other factors such as availability of supply, economics, and acceptance by regulatory agencies and the public.

2. *Need:* Reclaimed water may be the only feasible way of supplementing water resources in areas where additional freshwater resources are not available. Regulatory agencies are more likely to approve high-order types of reuse if there is a need for the water. It is prudent public health practice not to expose the public to substantial risks in the absence of a demonstrated need to do so.

3. *Availability and reliability of supply:* Reclaimed water customers can be assured of receiving their allocation of water. Interruptions in the production of reclaimed water are usually very short term and can be overcome by providing adequate storage facilities or by having an alternative source of water for emergency situations. The reclaimed water supply may be more reliable than the freshwater supply in times of water shortage.

4. *Economics:* Reclaimed water may be the most economical option for increasing water resources in a community. The incremental cost of upgrading

wastewater treatment, if any, and providing reclaimed water for many nonpotable uses is generally lower than the cost of providing the same quantity of potable water. Cost savings can accrue to the producer, the user, and the community in general. The producer may realize savings related to lessened treatment and disposal costs and the sale of reclaimed water. Reclaimed water is typically priced less than potable water, sometimes as an incentive to use the water. The community benefits by conserving valuable sources of freshwater for potable purposes, thereby reducing the amount of freshwater that must be treated to a potable level and eliminating or delaying the costs associated with obtaining additional sources of freshwater.

5. *Public and regulatory acceptance:* The public supports wastewater reuse if it is assured that the reuse will not present unreasonable health risks. Regulatory agencies have provided this assurance for many types of nonpotable reuse. Public awareness of the advantages and risks associated with wastewater reuse is crucial for widespread acceptance and implementation of wastewater reuse.

6. *Pollution abatement:* Population increases, identification of environmentally sensitive areas, public awareness, and more restrictive state and federal discharge standards all contribute to costly treatment for discharge to receiving waters. In some cases, discharges are being prohibited. Reuse may be less costly than treatment for disposal of effluent and often offers an expedient approach to pollution abatement. Under such conditions, reuse not only provides an additional water supply, but it also reduces overall costs to the community and eliminates a source of contamination in surface waters.

7. *Conservation:* Utilizing reclaimed water for nonpotable purposes can significantly reduce the freshwater demand, thereby conserving high-quality sources for potable purposes.

8. *Successful experiences:* While research and pilot studies provide useful and necessary information on many types of reuse, the ultimate test is full-scale operation. Existing projects provide answers to many questions that cannot be otherwise answered regarding health and environmental effects, economic concerns, reclaimed water quality, treatment reliability, and public acceptance.

III. Health Assessment

A. Chemical Constituents

The chemical constituents are a major concern when reclaimed water is used for direct or indirect potable reuse and may also affect the acceptability of reclaimed water for food crop irrigation. The mechanisms of food crop contamination include physical contamination, where evaporation and repeated application may result in a buildup of contaminants on crops; uptake through the roots from the applied water or the soil; and foliar uptake. With the exception of possible inhalation of volatile organics from indoor exposure, chemical concerns are less important where reclaimed water is not to be consumed.

1. Inorganics

In general, the health hazards associated with the ingestion of inorganic components, either directly or through food, are well established and the U.S. Environmental Protection Agency (EPA) has set drinking water maximum contaminant levels (MCLs) for the elements of concern. The concentrations of trace elements will vary in municipal sewage depending on the nature and quantity of industrial discharges to the sewerage system. Wastewater treatment facilities can generally reduce trace elements to below the recommended levels for irrigation and drinking water with existing technology.

Sodium salts are ubiquitous in the water environment. Sodium has long been linked to hypertension, and physicians recommend restricted sodium intakes for persons suffering from hypertension, edema associated with congestive cardiac failure, and women with toxemias of pregnancy. For restricted diets, the recommended sodium intake from sources other than water is 500 mg/day. Diets for these individuals permit sodium concentrations of 20 mg/liter in drinking water and water used for cooking.

There is a paucity of information regarding the health significance of many of the constituents that may be present in wastewater used for crop irrigation. Several trace elements, such as cadmium, copper, and selenium, are known to be phytotoxic at low concentrations. Some of the trace constituents accumulate in particular crops, thus presenting health hazards to both grazing animals and humans. For example, once in the soil system, some plants, such as clovers and grasses, will take up molybdenum and other heavy metals to concentrations that are toxic to the plant consumer but not to the plant.

2. Organics

The health effects resulting from organic constituents are of primary concern for indirect or direct potable reuse but, as with certain inorganic constituents, may also be of concern where reclaimed water is utilized for food crop irrigation or where the organ-

ics may bioaccumulate in the food chain, for example, in fish-rearing ponds. The effects may be manifested as acute toxicity from short-term exposure or chronic health effects from long-term exposure that become apparent only after years of exposure. Although drinking water standards contain MCLs for some organic contaminants, compliance with existing standards alone would not assure that reclaimed water is safe for potable reuse.

Traditional measures of organic matter, such as biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total organic carbon (TOC), are widely used as measures of treatment efficiency and water quality for many nonpotable uses of reclaimed water, but they have little relevance to toxicity and health effects evaluation. The identification and quantification of extremely low levels of organic constituents in water is possible using sophisticated analytical instrumentation, such as gas chromatography/mass spectrometry (GC/MS) interfaced with computers. GC/MS analyses are costly and may require extensive and difficult sample preparation, particularly for nonvolatile organics.

In addition to the presence of specific known or suspected carcinogenic, mutagenic, and teratogenic organic compounds in wastewater, organic precursor compounds are present that can be transformed into chlorinated organic species where chlorine is used for disinfection purposes. To date, most attention has focused on the trihalomethane (THM) compounds, a family of organic compounds typically occurring as chlorine or bromine substituted forms of methane. Chloroform is the most prevalent THM compound and has been implicated as a carcinogenic agent in the development of cancer of the liver and kidney.

Although a wide range of specific organic constituents has been identified in wastewater at low levels, the organic fraction remains largely unidentified. Laboratory studies have shown nonvolatile fractions to be mutagenic using the Ames test, which is a short-term toxicity assay using *Salmonella* bacteria as the test organism. Nonvolatile fractions have also been shown to be mutagenic in mammalian cells *in vitro*, cytotoxic, and carcinogenic in animal species.

Results of epidemiological studies of populations receiving water considered to contain significant quantities of organic compounds have been inconclusive, although positive correlations were found in several studies. Causal relationships could not be proven on the basis of the results of the studies. The National Academy of Sciences (NAS) concluded that the associations were small and had a wide margin of error, which could be attributed to the methodological difficulties inherent in most epidemiological studies. NAS also concluded that, when viewed collectively, the epidemiological studies provided sufficient evidence for maintaining the hypothesis that there may be a potential health risk.

While technology regarding trace organics has advanced substantially in the last decade, uncertainties persist regarding the range of compounds; additive, synergistic, or antagonistic effects; and the total health significance of trace organics. The ability to identify and quantify low levels of contaminants in water has outstripped our capability to evaluate and interpret the significance of the levels measured in assessing potential health effects.

B. Pathogenic Microorganisms

The principal infectious agents that may be present in raw sewage can be classified into three broad groups: bacteria, parasites (protozoa and helminths), and viruses. Table III summarizes the major infectious agents potentially present in raw domestic wastewater.

Diseases can be transmitted to humans either directly by skin contact, ingestion, or inhalation of infectious agents in reclaimed water or indirectly by contact with objects previously contaminated. Whether illness occurs depends on a series of complex interrelationships between the host and the infectious agent. Specific variables include the numbers of the invading microorganism (dose), the numbers of organisms necessary to initiate infection (infective dose), the organism's ability to cause disease (pathogenicity), and the relative susceptibility of the host.

Susceptibility is highly variable and dependent upon both the general health of the subject and the specific pathogen in question. Infants, elderly persons, malnourished persons, and persons with concomitant illnesses are more susceptible than healthy adults. It is impossible to accurately predict the type or concentration of pathogens in raw wastewater. Concentration ranges of some microorganisms that may be present in untreated municipal wastewater are given in Table IV. The infectious doses of selected pathogens are presented in Table V.

Under favorable conditions, pathogens can survive for long periods of time on crops or in water or soil. Factors that affect survival include the number and type of organism, soil organic matter content, temperature, humidity, pH, amount of rainfall, amount of sunlight, protection provided by foliage, and competitive microbial fauna and flora. Pathogen survival times on vegetation and in water and soil are presented in Table VI.

TABLE III. Major Pathogens Potentially Present in Wastewater

Pathogen	Disease
Protozoa	
Entamoeba histolytica	Amebiasis (amebic dysentery)
Giardia lamblia	Giardiasis
Balantidium coli	Balantisiasis (dysentery)
Cryptosporidium	Diarrhea, fever
Helminths	
Ascaris lumbricoides (roundworm)	Ascariasis
Ancylostoma duodenale (hookworm)	Ancylostomiasis
Necator americanus (roundworm)	Necatoriasis
Ancylostoma (spp.) (hookworm)	Cutaneous larva migrams
Strongyloides stercoralis (threadworm)	Strongyloidiasis
Trichuris trichiura (whipworm)	Trichuriasis
Taenia (spp.) (tapeworm)	Taeniasis
Enterobius vermicularis (pinworm)	Enterobiasis
Echinococcus granulosus (spp.) (tapeworm)	Hydatidosis
Campylobacter jejune	Gastroenteritis
Bacteria	
Shigella (4 spp.)	Shigellosis (dysentery)
Salmonella typhi	Typhoid fever
Salmonella (1700 spp.)	Salmonellosis
Vibro cholerae	Cholera
Escherichia coli (enteropathogenic)	Gastroenteritis
Yersinia enterocolitica	Yersiniosis
Leptospira (spp.)	Leptospirosis
Viruses	
Enteroviruses (71 types) (polio, echo, coxsackie, new enteroviruses)	Gastroenteritis, heart anomolies, meningitis, others
Hepatitis A virus	Infectious hepatitis
Adenovirus (40 types)	Respiratory disease
Rotavirus	Gastroenteritis
Parvovirus (3 types)	Gastroenteritis
Norwalk agent	Diarrhea, vomiting, fever
Reovirus (3 types)	Not clearly established
Astrovirus	Gastroenteritis
Calicivirus	Gastroenteritis

C. Aerosols

Viruses and most pathogenic bacteria are in the respirable size range; hence, a possible direct means of human infection by aerosols is by inhalation. Infection or disease can be contracted indirectly by deposited aerosols on surfaces such as food, vegetation, and clothes. The infective dose of many pathogens is lower for respiratory tract infections than for infections via the gastrointestinal tract.

In general, bacteria and viruses in aerosols remain viable and travel farther with increased wind velocity, increased relative humidity, lower temperature, and lower solar radiation. Other important factors include the initial concentration of pathogens in

TABLE IV. Microorganism Concentrations in Raw Sewage

Organism	Concentration (number/100 ml)
Coliform	10^4-10^7
Fecal streptococci	10^4-10^6
Shigella	1–10
Salmonella	400–8000
Helminth ova	1–10
Enteric virus	100–100,000
Giardia lamblia cysts	$50-10^4$
Entamoeba histolytica cysts	0–10

TABLE V. Infectious Doses of Selected Pathogens

Organism	Infectious dose
Escherichia coli	10^6-10^{10}
Clostridium perfringens	1×10^{10}
Salmonella typhi	10^4-10^7
Vibrio cholerae	10^3-10^7
Shigella flexneri 2A	180
Entamoeba histolytica	20
Shigella dysentariae 1	10
Giardia lamblia	<10
Viruses	1–10

TABLE VI. Typical Pathogen Survival Times

Type of organism	Media	Usually less than	Maximum
Bacteria	Soil	2 months	>1 year
	Vegetation	1 month	6 months
	Water	2 months	4 months
Protozoa	Soil	15 days	1 month
	Vegetation	2 days	10 days
	Water	15 days	>2 months
Helminth ova	Soil	2 years	7 years
	Vegetation	1 month	6 months
	Water	1 year	>1 year
Viruses	Soil	3 months	>6 months
	Vegetation	1 month	>4 months
	Water	2 months	>8 months

the wastewater and droplet size. The amount of water that is aerosolized during spray irrigation varies from less than 0.1% to almost 2%. Aerosols can be transmitted for several hundred meters under optimum conditions.

The use of the traditional indicator organisms to predict human exposure via aerosols may result in the significant underestimation of pathogen levels. Some types of pathogenic organisms survive the wastewater aerosolization process much better than the indicator organisms.

Because there is limited information available regarding the health risks associated with wastewater aerosols, health implications are difficult to assess. The research conducted to date indicates that the health risk associated with aerosols from sewage effluent spray irrigation sites is low, particularly for wastewater that has been disinfected. However, until more sensitive and definitive studies are conducted to fully evaluate the ability of pathogens contained in aerosols to cause disease, the general practice is to limit exposure to aerosols through design or operational controls.

D. Disease Incidence Related to Wastewater Reuse

There is epidemiological evidence indicating that the reuse of municipal wastewater for the irrigation of fodder and food crops has resulted in the transmission of disease. The majority of documented disease

outbreaks resulted from bacterial or parasitic contamination. In almost all cases, either raw sewage or undisinfected effluent was the source of irrigation water. Reasonable standards of personal hygiene, for example, use of protective clothing, change of clothing at the end of the work period, avoidance of exposure to reclaimed water where possible, and care in handwashing and bathing following exposure and prior to eating, appear to be effective in protecting the health of workers at water reuse sites, regardless of the level of treatment provided. There have not been any confirmed cases of disease in California resulting from the use of reclaimed wastewater, where it has been used for a variety of uses involving direct or indirect human contact for many years.

There is little information concerning the occurrence of viral disease outbreaks resulting from the reuse of wastewater, but the water route of transmission has been implicated in outbreaks of infectious hepatitis and poliomyelitis. The study of low-level or endemic occurrence of waterborne virus diseases has been virtually ignored for several reasons.

1. Present virus detection methods are not sufficiently sensitive to accurately detect low concentrations of viruses in large volumes of water.

2. Enteric virus infections are often not apparent, thus making it difficult to establish the endemicity of such infections.

3. The apparently mild nature of most enteric virus infections precludes reporting by the patient or the physician.

4. Current epidemiological techniques are not sufficiently sensitive to detect low-level transmission of viral diseases through water.

5. Damage caused by enteroviral infections may not become obvious for several months or years.

6. Once introduced into a population, person-to-person contact becomes a major mode of transmission of an enteric virus, thereby obscuring the role of water in its transmission.

IV. Removal of Wastewater Constituents

Figure 2 depicts a generalized flow sheet for municipal wastewater treatment. The acceptability of reclaimed water for any intended reuse is dependent on the physical, biological, and chemical characteristics of the treated wastewater. Control of pathogenic organisms is of prime concern for uses where public

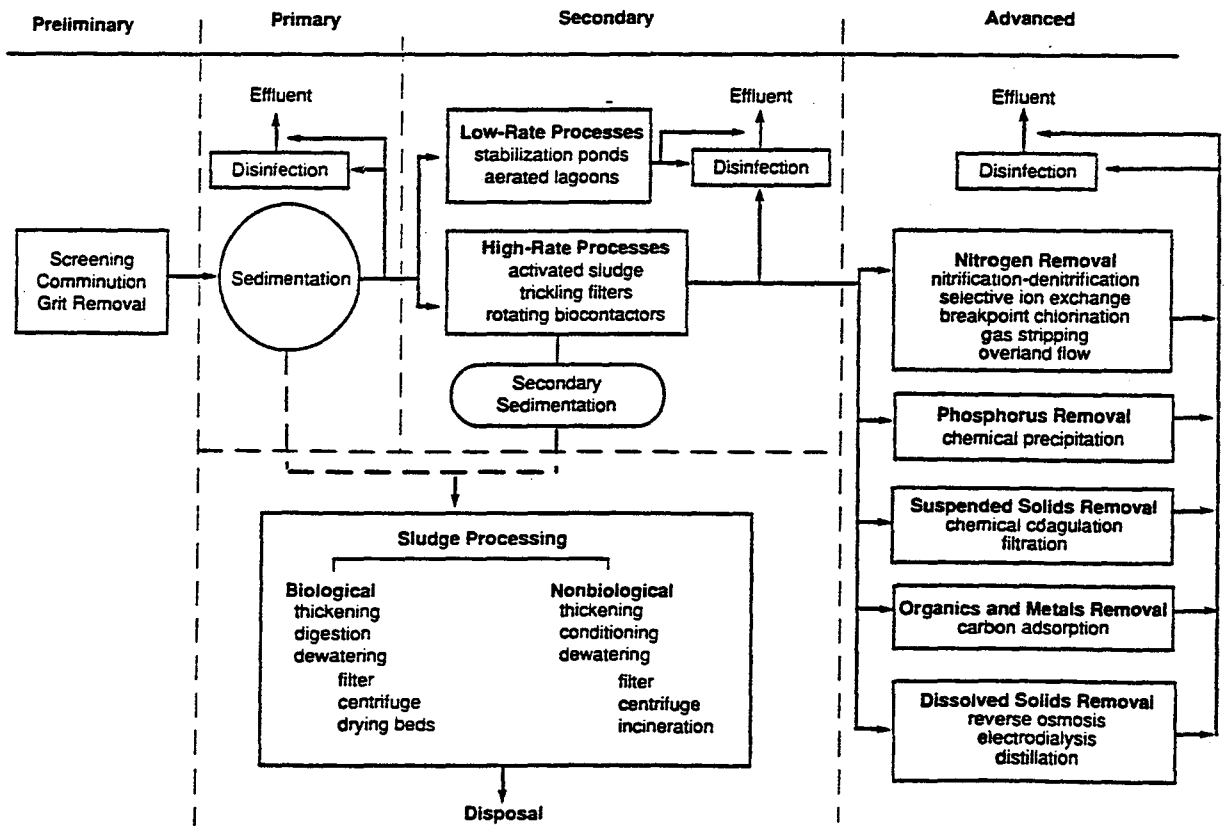

FIG. 2. Generalized flow sheet for municipal wastewater treatment. [From California State Water Resources Control Board (1984). "Irrigation with Reclaimed Water—A Guidance Manual." Report No. 84-1 wr. Sacramento, California.]

contact is likely, whereas possible adverse effects of inorganic or organic constituents on crops or other plants are a consideration for irrigation uses. Removal of organic matter is necessary for a variety of reasons. Organic matter can present aesthetic and nuisance problems, provide food for microorganisms, adversely affect disinfection processes, make the water unsuitable for some industrial or other uses, consume oxygen, and may result in acute or chronic adverse health effects if reclaimed water is used for potable purposes.

The removal of suspended matter from reclaimed water is not only of aesthetic importance but also has an important functional significance. Organic contaminants, heavy metals, etc., are associated with and adsorbed by particulates; hence, removal of particulates generally reduces chemical contamination. There is a correlation between removal of suspended matter, whether organic or inorganic, and other particulates, such as bacteria and viruses. It is relevant that suspended matter can shield microorganisms from disinfectants. Reliable instrumentation is available for continuous, on-line measurement of turbidity, and as a result, turbidity has found wide application as a water quality parameter at a number of water reclamation facilities. However, a low turbidity value does not indicate that the reclaimed water is devoid of suspended particles, including microorganisms. As such, turbidity is not used as an indicator of microbiological quality but rather as a quality criterion for wastewater prior to disinfection.

A. Microorganisms

Removal of microorganisms by conventional treatment processes varies greatly depending on the microorganism concentration in the raw sewage and unit process operational procedures. Table VII lists typical treatment efficiency data from the literature.

Primary treatment has little effect on the removal of most biological species that may be present in the wastewater. However, some protozoa and parasite ova and cysts will settle out during primary treatment, and some particulate-associated microorganisms may be removed with settleable matter. Primary treatment does not effectively reduce the level of viruses in sewage.

Conventional secondary treatment processes reduce the concentration of microorganisms by predation or adsorption to particulates that are subsequently removed by sedimentation. Biological treatment, including secondary sedimentation, and lagoon systems are capable of removing over 90% of the bacterial organisms and viruses. In general, activated sludge processes are more effective in reducing microbial populations than are trickling filters or rotating biological contactors. Removal by lagoon systems is erratic, but stabilization pond systems having extensive retention times can effectively reduce pathogen concentrations to very low levels. Secondary effluents can contain a significant number of pathogens, particularly bacteria and viruses. The literature indicates that the viral content of activated sludge effluent ranges from < 1 to approximately 150 viral units/liter and trickling filter effluent from 5 to about 300 viral units/liter.

Tertiary treatment by the unit processes of chemical coagulation, sedimentation, and filtration has been demonstrated to remove up to 2 logs (99.5%) of seeded viruses. This treatment chain reduces the turbidity of the wastewater to very low levels, thereby enhancing the efficiency of the subsequent disinfection process. Chemical coagulation and sedimentation alone can remove up to 2 logs (99%) of the viruses, although the presence of organic matter can significantly decrease the amount of viruses removed. Direct filtration, that is, chemical coagulation and filtration, has also been shown to remove up

TABLE VII. Removal of Microorganisms by Conventional Wastewater Treatment

		Secondary treatment	
Infectious agent	Primary treatment (% removal)	Activated sludge (% removal)	Trickling filter (% removal)
Coliform	<10	0–99	85–99
Salmonella	0–15	70–99+	85–99+
Mycobacterium tuberculosis	40–60	5–90	65–99
Shigella	15	80–90	85–99
Entamoeba histolytica	0–50	Limited	Limited
Helminth ova	50–98	Limited	60–75
Enteric viruses	Limited	0–99	0–85

to 2 logs (99%) of seeded viruses. The primary purpose of the filtration step is not to remove viruses but to remove floc and other suspended matter, which coincidentally may contain adsorbed or enmeshed viruses.

Virus inactivation under alkaline pH conditions can be accomplished using lime as a coagulant. pH values of 11 to 12 are required before significant inactivation is obtained. The mechanism of inactivation under alkaline conditions is caused by denaturation of the protein coat and by disruption of the virus.

The purpose of most advanced treatment processes is to remove either inorganic or organic constituents. The removal of biological contaminants by these processes is incidental and, generally, not too great. An exception is reverse osmosis, which can be very effective in removing most viruses and virtually all larger microorganisms. Activated carbon adsorption has been shown to adsorb some viruses from wastewater, but the adsorbed viruses can be displaced by organic compounds and enter the effluent.

The most important process for the destruction of microorganisms is disinfection. In the United States, the most common disinfectant for both water and wastewater is chlorine. The efficiency of disinfection with chlorine is dependent upon the water temperature, pH, degree of mixing, time of contact, presence of interfering substances, concentration and form of the chlorinating species, and the nature and concentration of the organisms to be destroyed. In general, bacteria are less resistant to chlorine than are viruses, which in turn are less resistant than parasite ova and cysts.

The chlorine dosage required to disinfect a wastewater to any desired level is greatly influenced by the constituents present in the wastewater. Some of the interfering substances are organic constituents, which consume the disinfectant; particulate matter, which protects microorganisms from the action of the disinfectant; and ammonia, which reacts with chlorine to form chloramines, which are much less effective disinfectant species than free chlorine. In practice, the amount of chlorine added is determined empirically, based on desired residual and effluent quality, usually measured by total or fecal coliform concentration. Residual chlorine, which in low concentrations is toxic to many aquatic organisms, is easily controlled in reclaimed water by dechlorination, typically with sulfur dioxide.

The destruction of viruses by chlorine is highly variable, and the coliform test by itself does not give a reliable indication of the effectiveness of virus destruction by disinfection. Chemical coagulation and filtration followed by disinfection to very low coliform levels can remove or inactivate 5 logs (99.999%) of seeded viruses through these processes alone and, in conjunction with biological secondary treatment, produce effluent essentially free of measurable native, that is, naturally occurring, viruses.

Ozone, O_3, is a powerful disinfecting agent and a powerful chemical oxidant in both inorganic and organic reactions. Ozone destroys bacteria and viruses by means of rapid oxidation of the protein mass, and disinfection is achieved in a matter of minutes. Some disadvantages are that the use of ozone is relatively expensive and energy intensive, ozone systems are more complex to operate and maintain than chlorine systems, and ozone does not maintain a residual in water. Ozone is a highly effective disinfectant for advanced wastewater treatment plant effluent and is superior to chlorine with respect to virus inactivation, but it is not as effective a bactericide as chlorine.

The effectiveness of ultraviolet radiation as a disinfectant has been well established, as evidenced by its use at more than 120 small- to medium-size treatment plants in the United States. However, interference by suspended matter or dissolved organics limits the effective disinfection range. Even in relatively clean water, slimes tend to form on the quartz tube, thereby reducing its efficiency.

Other disinfectants, such as gamma radiation, bromine, iodine, and hydrogen peroxide, have been considered for the disinfection of wastewater but are not generally used because of economical, technical, operational, or disinfection efficiency considerations.

B. Inorganic Constituents

The quantities of inorganic constituents present in sewage effluents depend on several factors, but mainly on the source of wastewater and the degree of treatment. Residential use of water typically adds about 300 mg/liter of dissolved inorganic solids. Total dissolved solids, nitrogen, phosphorus, and other inorganic constituents may affect the acceptability of wastewater used for irrigation or other nonpotable purposes, whereas heavy metals and other potentially toxic substances also must be controlled for reuse systems involving eventual ingestion of the water.

The phosphates present in wastewater are largely in the form of orthophosphates, a significant amount of which are formed by the hydrolysis of polyphosphates during treatment. Ammonia is formed by the hydrolysis of urea and the biological decomposition of organic nitrogen compounds. The ammonia concentration is subsequently reduced by assimilation, volatilization, and conversion to nitrite and nitrate.

TABLE VIII. Average Process Removals of Various Inorganic Constituents

Constituent	Raw sewage concentration (mg/l)	Primary (%)	Activated sludge (%)	Trickling filter (%)	Filtration (%)
Ag	0.004–0.05	50	75	55	
As	<0.005–0.03	34	28		67
Cd	0.004–6.4	35	55	5	32
Cr	<0.05–6.8	40	70	19	53
Cu	<0.02–3.36	45	65	56	
Fe	0.5–6.5	50	60	46	56
Hg	0–0.125	11	13	0	33
Mn	0.05–0.15	24	30	16	80
Mo	<0.001–0.2	22	23	15	
Ni	0.002–1.5	25	22	20	
Pb	0.05–1.27	53	58	40	16
Se	<0.005–0.11	0	7		90
Zn	0.01–8.31	42	55	56	
P	4–50	27	45		57
NH_{3-N}	10–85	18	63		83

Unlike ammonia and phosphate, nitrite and nitrate are not added to water in substantial amounts during its use but are formed by the microbial oxidation of ammonia.

The effect of conventional treatment on various constituents is shown in Table VIII. Activated sludge treatment is more efficient in removing heavy metals than trickling filtration. The removal of heavy metals during primary and secondary treatment can proceed by two mechanisms: precipitation of metal hydroxides, which are removed with the sludge; and adsorption of soluble trace metals by the sludge. The precipitation of metal hydroxides is governed by the concentration of the metal ion in solution and the pH. In general, the solubility of the metal decreases as the pH increases.

The removal of chromate in sewage depends upon the reduction of hexavalent chromium to a trivalent form and subsequent precipitation of trivalent chromium. Hexavalent chromium concentrations of up to 0.5 ppm are usually completely removed by the activated sludge process. At higher feed concentrations, an increasing but variable amount of chromium passes through the system.

Chemical coagulation and sedimentation can substantially reduce heavy metals in wastewater. Because many of the trace metals form insoluble hydroxides at pH 11 or greater, lime coagulation is effective, albeit somewhat selective. Coagulation using alum as the coagulant has been demonstrated to provide substantial removals of lead, copper, trivalent chromium, and zinc.

Carbon adsorption treatment will remove several metal ions, particularly cadmium, hexavalent chromium, silver, and selenium. Activated carbon has been used to remove un-ionized species, such as arsenic and antimony, from an acidic stream, and it also reduces mercury to low levels, particularly at low pH values. Ion exchange and reverse osmosis are very effective processes for removing metals from water, removing more than 95% of most heavy metals.

Nitrogen may be present in wastewater in several forms, for example, organic nitrogen, ammonium ion, or ammonia gas. Nitrogen may be removed by biological, chemical, or physical treatment methods. Common methods capable of removing 75–90+% of the nitrogen include nitrification–denitrification during biological treatment, air stripping, selective ion exchange using cliniptilolite, and breakpoint chlorination. Breakpoint chlorination is capable of removing virtually all the ammonia nitrogen in wastewater, but the process consumes large amounts of chlorine, usually limiting its application to situations where stringent discharge requirements must be met and effluent ammonia concentrations have already been reduced to relatively low levels.

The most common method of phosphorus removal is by chemical coagulation and clarification using lime, alum, or ferric chloride as the coagulant. This treatment process typically removes more than 90% of the phosphorus in the wastewater, and phosphates are generally reduced to 2–3 mg/liter or less in the effluent. Effluent phosphorus levels of less than 0.5 mg/liter are achievable by chemical precipitation methods.

C. Organic Constituents

The organic makeup of raw sewage includes naturally occurring humic substances, fecal matter, food from garbage grinders, liquid detergents, oils, grease, and other substances that one way or another become part of the sewage stream. Industrial wastes can contribute significant quantities of synthetic organic compounds.

The need to remove organic constituents is related to the use of the reclaimed water. Some of the adverse effects associated with organic substances include the following.

1. Aesthetically displeasing: they may be malodorous and impart color to the water.
2. A nuisance: deposits of organic matter may present vector control and eventually health problems.
3. Clogging: particulate matter may clog sprinkler heads or accumulate in soil and affect permeability.
4. Oxygen consuming: they may affect aquatic life in streams and lakes.
5. Use limiting: many industrial applications cannot tolerate water high in organic content.
6. Disinfection effects: organic matter is oxidized by chlorine, thereby making less available for disinfection purposes.
7. Health effects: ingestion of water containing certain organic compounds may result in acute or chronic health effects.

The bulk of the data generated regarding the quantities of organic substances in domestic wastewater is in terms of gross parameters, such as BOD, COD, TOC, and total suspended solids (TSS). Typical ranges for these constituents in raw sewage and the percentage of their removals by conventional processes are shown in Table IX.

Primary treatment, including grit removal, merely reduces the concentration of settleable matter and has no effect on dissolved organic constituents. The concentration and form of the organic constituents have a great effect upon removal by a physical settling process.

The removal of organic substances by well-operated biological secondary treatment processes is on the order of 85–90% for both BOD and COD. Trickling filters are not as effective as activated sludge processes in removing soluble organics because of less contact between the organic matter and microorganisms. Activated sludge treatment can reduce the soluble BOD fraction to 1–2 mg/liter, while the trickling filter process reduces the soluble BOD to 10–15 mg/liter. Biological treatment, including secondary sedimentation, typically reduces the total BOD to 15–25 mg/liter, COD to 40–70 mg/liter, and TOC to 15–25 mg/liter.

Advanced wastewater treatment processes, such as chemical coagulation, microstraining, sand or mixed media filtration, and ion exchange, are not designed to remove many organic substances, particularly soluble organics. When these processes follow conventional secondary treatment, they typically remove 40 to 85% of the total BOD, COD, and TOC.

One of the most effective advanced wastewater treatment processes for removing biodegradable and refractory organic constituents is the use of granular activated carbon. Carbon adsorption can reduce the levels of synthetic organic chemicals in wastewater by 75–85%. The basic mechanism of removal is by adsorption of the organic compounds onto the carbon. Carbon adsorption preceded by conventional secondary treatment and filtration can produce an effluent with a BOD of 0.1–5.0 mg/liter, a COD of 3–25 mg/liter, and a TOC of 1–6 mg/liter.

The major organic fraction adsorbed by activated carbon is in the 100 to 10,000 molecular weight range. Low molecular weight fractions, consisting of mostly polar organic compounds, and compounds having molecular weights greater than 50,000 are poorly adsorbed. Other molecules having highly branched structures are removed much more slowly than those of identical molecular weight but with configurations that permit coiling and compactness that result in high rates of diffusion into the pores of the carbon. Chlorinated organic compounds are generally well adsorbed by granular activated carbon.

TABLE IX. Average Process Removals of Gross Constituents

Constituent	Raw sewage concentration (mg/l)	Primary (%)	Activated sludge (%)	Trickling filter (%)	Filtration (%)
BOD	100–400	35–70	80–95	70–95	35–45
COD	200–900	20–60	70–90	70–90	30–40
TOC	50–200	50–60	70–90		30–40
TSS	200–600	50–60	60–95	40–85	60–85

The removal of organic compounds by reverse osmosis (RO) is influenced by the size, shape, chemical characteristics, and concentration of organic species as well as the physical and chemical characteristics of the feed water and type of reverse osmosis unit employed. Because of the nature of the RO process, feed water must be of a fairly high quality to prevent membrane clogging and deterioration. RO can readily remove over 90% of the gross organics and with proper pretreatment can reduce TOC levels to less than 1.0 mg/liter.

V. Reuse Applications

A. Agricultural Irrigation

In many parts of the United States, the demand for irrigation water is nearing or exceeds the resources from freshwater supplies. Reclaimed water provides a constant and reliable source of water, even during drought conditions. The nitrogen, phosphorus, and potassium in reclaimed waters provide valuable nutrients to plants that may otherwise have to be provided by the use of fertilizers and can result in considerable cost savings. The overall value of nutrients in filtered secondary effluent has been estimated to range from \$20–\$45/acre-foot (\$16–\$36/1000 m^3) of reclaimed water. The cost of reclaimed water is often less than the real cost of subsidized agricultural irrigation water or the cost of potable water used for irrigation.

In the United States, agricultural irrigation accounts for about 90 bgd (340×10^6 m^3/d) of the total consumptive use of approximately 110 bgd (420×10^6 m^3/d). Agricultural irrigation represents the largest current use of reclaimed water. In California alone, almost 180 mgd (0.7×10^6 m^3/d) of reclaimed water are used for agricultural purposes at over 200 sites.

Current standards are generally based on public health aspects associated with public or worker protection during application, animal or human consumption of the crops, and contamination of potable surface water or groundwater supplies. Regulatory constraints may impact the types of crops that can be irrigated with the reclaimed water, the method of irrigation, and agricultural practices such as harvesting techniques. Agronomic factors, for example, salinity effects, may limit the acceptability of the reclaimed water for agricultural irrigation.

Primary or undisinfected secondary effluent has been used for the surface irrigation of fodder, fiber, and seed crops for over 70 yr without any observed detrimental health effects. With proper application and use area controls, human contact with the wastewater is minimal. Allowing the fields to dry before grazing or harvest for fodder crops substantially reduces the number of viable pathogens on the crop before animal consumption. Similarly, this quality of effluent presents limited health concerns for the surface irrigation of orchards and vineyards if fallen fruit is prohibited from being harvested. While absorption of enteric viruses by plants is theoretically possible, the likelihood of translocation of pathogens through trees, plants, or vines to edible portions of the crops is extremely low.

The risks vary depending on the type of crop and method of irrigation. If the crop is subjected to sufficient commercial processing to destroy pathogenic microorganisms, it may not be necessary to provide a highly disinfected effluent, even though occasional contact may occur between the wastewater or contaminated soil and the crop as a result of splashing, vector transmission, windblown dust, or infrequent flooding caused by overirrigation.

Spray irrigation of food crops and irrigation of root crops result in direct contact between the wastewater and the crops. Organisms contaminating food crops remain viable on the food surface unless they succumb to dessication, exposure to sunlight, starvation, predation by other organisms, or the action of chemical agents. The reliability and completeness of pathogen inactivation by these mechanisms is arguable, and most regulatory agencies either prohibit the spray irrigation of food crops sold or eaten raw or impose restrictive wastewater treatment and effluent quality requirements.

The chemical quality of reclaimed water used for agricultural purposes has not been well defined. Of major concern are salinity, suspended solids, heavy metals, organic constituents, and certain inorganic elements and compounds. The U.S. EPA has recommended limits for some constituents in irrigation water, as shown in Table X.

The inorganic chemical quality of irrigation waters can be classified according to salinity, specific ion toxicity, and permeability hazard. Salinity is a particular concern in the use of reclaimed water since it generally has a higher salt content than freshwater. Salinity control can be an important criterion for agricultural irrigation with reclaimed water. The total dissolved solids (TDS) of the reclaimed water depend principally on the characteristics of the potable supply. Where the TDS are high, the problem is aggravated by poor leaching of the soil and high evapotranspiration rates. Food crops are generally more sensitive to TDS than pasture or grasses.

If excessive quantities of soluble salts accumulate

TABLE X. Recommended Limits for Trace Elements in Reclaimed Water Used for Irrigation[a]

Constituent	Long-term use[b] (mg/liter)	Short-term use[c] (mg/liter)
Aluminum	5.0	20.0
Arsenic	0.10	2.0
Beryllium	0.10	0.5
Boron	0.75	2.0
Cadmium	0.01	0.05
Chromium	0.1	1.0
Cobalt	0.05	5.0
Copper	0.2	5.0
Fluoride	1.0	15.0
Iron	5.0	20.0
Lead	5.0	10.0
Lithium	2.5	2.5
Manganese	0.2	10.0
Molybdenum	0.01	0.05
Nickel	0.2	2.0
Selenium	0.02	0.02
Vanadium	0.1	1.0
Zinc	2.0	10.0

Other constituents	Recommended limit
pH	4.5–9.0
Fecal coliform	1000/100 ml
TDS	500–5000 mg/liter

[a]From the National Academy of Sciences–National Academy of Engineering (1973). "Water Quality Criteria 1972." U.S. Environmental Protection Agency, Washington, D.C.
[b]For water used continuously on all soils.
[c]For water used for a period of up to 20 yr on fine-textured neutral or alkaline soils.

in the root zone, the osmotic potential of the soil solution becomes excessively high and water becomes less available to plants. As the amount of dissolved salts in irrigation water increases, crop yields decrease and eventually a point is reached where plant life cannot be sustained. The limiting concentrations depend on the plant, type of soil, climatological conditions, and amount of water applied. Because of the osmotic pressure effect of salts in water, more frequent irrigations are required than under normal nonsaline irrigation conditions. Under saline water irrigation conditions, a sufficient amount of water has to be applied to leach salts beyond the root zone to maintain a favorable growth environment. Proper drainage of the soil may be as important a factor for crop growth as the salt content of the irrigation water.

The effect of various constituents in the water varies according to type of crop irrigated. Many plants are sensitive to salts, which can stunt growth, cause leaf burn and leaf drop, and cause stem dieback. Some plants exhibit a specific toxicity to certain ions, such as chloride, boron, and sodium. Chlorides are present in nearly all waters. They are not necessary for plant growth and in high concentrations cause subnormal growth rates and burning of leaves. Foliar adsorption of chlorides in sprinkler irrigation may cause plant damage at fairly low concentrations. The sodium ion may also be toxic to certain shrubs.

Boron occurs in the form of borates or boric acid. This element is essential in minor amounts for the growth of plants. It is extremely toxic to most plants at higher concentrations. Limits for most irrigated crops vary from 0.5 to 2.0 mg/liter. Citrus crops, particularly lemons, are sensitive to boron in concentrations exceeding 0.5 mg/liter.

Water containing a high percentage of sodium has an adverse effect upon the physical structure of clay soils by dispersing the soil colloids. This retards the movement of water and the leaching of salts and makes the soils difficult to work. The bicarbonate ion also has an adverse effect on the permeability of certain soils.

The fertilizer value of nutrients in wastewater is generally considered to be a benefit, but high nitrogen concentrations can be detrimental. Nitrogen concentrations below 5 mg/liter are generally ac-

TABLE XI. Nutrient Uptake Rates of Crops

	Uptake (lb/acre/yr)[a]		
Type of crop	Nitrogen	Phosphorus	Potassium
Forage crops	100–600	15–75	90–290
Field crops	60–175	10–25	20–290

[a]lb/acre/yr = 1.12 kg/ha/yr.

ceptable, but concentrations above 30 mg/liter may present severe problems. High nitrogen concentrations can cause excessive vegetative growth at the expense of fruit production, may delay maturity, may result in reduced sugar or starch content of some food crops, and can adversely affect flavor and texture of food crops. On the other hand, fodder crops usually benefit from large amounts of nitrogen. Ranges of nutrient uptake rates for forage crops and field crops are shown in Table XI.

The extent to which organic chemicals in reclaimed water may be taken up by plants is not well understood. Plants are known to take up many pesticides through roots and translocate them within the plant. Unless industrial discharges add unusually high amounts of organic constituents to the wastewater, such constituents are not normally present at levels adequate to adversely affect either crops, vegetation, or consumers. Secondary effluent generally does not present problems of organic contamination.

Free available chlorine in concentrations greater than 0.05 mg/liter may cause leaf tip burn and damage to some sensitive crops. Reclaimed water usually contains combined chlorine residuals, which have not been observed to cause crop damage at the levels normally present in treated wastewater.

Surface, spray, and drip irrigation systems each have advantages and disadvantages. Spray irrigation via center pivot, solid set, moving gun, or wheel line may limit the type of food crops that can be irrigated with reclaimed water and may be subject to nozzle clogging by suspended matter, and the aerosols and windblown spray created may result in the imposition of buffer zone requirements. Flood or ridge and furrow irrigation may demand delivery of large quantities of irrigation water over a short time period. Drip irrigation utilizes much less water than the other types of irrigation—from 0.5 to 2 gal (2 to 8 liters) of water per hour per emitter—but often requires extensive pretreatment of the wastewater. Clogging of drip or spray systems can occur as a result of suspended solids, chemical precipitation, and biological growths. Maintenance of a chlorine residual can control bacteria and algal growths in irrigation lines.

There are numerous examples of successful agricultural irrigation projects in the United States. Bakersfield, California, has used effluent for irrigation since 1912. During the early years, first raw sewage and then primary effluent were used for irrigation. At the present time, approximately 5100 acres (2100 ha) of corn, alfalfa, cotton, barley, sorghum, and sugar beets are irrigated with more than 17 mgd (64,000 m^3/d) of primary and secondary effluent from three treatment plants. With the exception of cotton, crop yields exceed the county averages without the addition of supplemental fertilizer. The cotton yields have been lower than normal because the high nitrogen content of the wastewater directed growth to the plant rather than to the cotton bolls. To solve that problem, the cotton crop is irrigated with wastewater only early in the growing season, and well or canal water is used during the setting of the bolls.

The long-term application at Bakersfield has resulted in increased concentrations of surface adsorbed and precipitated heavy metals in the soil surface, although only zinc and lead levels are markedly different from those in soils irrigated with well water. Concentrations of extractable phosphorus have increased throughout the soil profile.

Trickling filter effluent from the city of Lubbock, Texas, has been used to irrigate approximately 3000 acres (1200 ha) of cotton, grain sorghum, and wheat on a local farm since 1938. The use of reclaimed water has reportedly increased crop yields without commercial fertilizer and improved soil conditions. Increasing flows through the years eventually led to hydraulic overloading at the farm, which was remedied by expanding the system in 1982 by an additional 2700 acres (1100 ha) at another site, allowing a total of 15 mgd (60,000 m^3) of reclaimed water to be used for agricultural purposes.

A 7-yr agricultural reuse demonstration study conducted at Castroville, California was completed in 1987. Significant study findings were that no pathogenic organisms were detected in the reclaimed water, and spray irrigation with the reclaimed water did not adversely affect soil permeability, did not result in heavy metal accumulation in the soil or plant tis-

sue, and did not adversely affect crop yield, quality, or shelf life. The study investigators concluded that filtered, secondary effluent meeting a total coliform limit of 2.2/100 ml was acceptable for the spray irrigation of food crops eaten raw. As a result of this study, a 30-mgd (110,000 m^3/d) wastewater reclamation plant is currently under design, with the intent of utilizing the effluent for crop irrigation in the Salinas Valley.

B. Landscape (Urban) Irrigation

Landscape irrigation involves the spray irrigation of golf courses, parks, cemeteries, school grounds, freeway medians, residential lawns, and similar areas. The concern for microorganisms is somewhat different than for agricultural irrigation in that landscape irrigation frequently takes place in urban areas where control over the use of the reclaimed water is more critical, while the chemical composition of the irrigation water is not usually limiting. Depending on the area being irrigated, its location relative to populated areas, and the extent of public access or use of the grounds, the microbiological requirements and operational controls placed on the system may differ. Irrigation of areas not subject to public access has limited potential for creating public health problems, whereas the microbiological requirements generally increase as the expected level of human contact with the reclaimed water increases.

Buffer zones may be required around spray irrigation sites if the wastewater receives minimal disinfection. Disinfected secondary effluent is generally acceptable for areas where public access is limited, direct contact with the water can be avoided, and sufficient time is allowed for the grounds to dry before use, such as at golf courses and cemeteries. Parks, playgrounds, schoolyards, and similar areas generally have ready access and are more intensely used by children and others. Hence, the microbiological requirements for these types of landscape irrigation tend to be more restrictive, although there is no consensus among the states. Requirements range from secondary treatment with a fecal coliform limit of 200/100 ml in the reclaimed water to advanced wastewater treatment with a total coliform limit of 2.2/100 ml in the reclaimed water.

Landscape irrigation use area controls frequently include public notification, off-hours irrigation, buffer zones, fencing, minimization of windblown spray, cross-connection control provisions, elimination of hose bibbs, and other means to prevent public contact with, or access to, the reclaimed water.

Golden Gate Park in San Francisco, California, has been using disinfected, activated sludge effluent periodically since 1932. Approximately 1 mgd (4,000 m^3/d) are discharged to ornamental lakes where it is mixed with well water and subsequently used to supply about 25% of the park's water needs for horticultural purposes. The reclaimed water is very low in solids and oxygen-consuming substances. It contains 40–60 mg/liter of total nitrogen and an appreciable amount of phosphate, making it desirable for general irrigation when mixed with fresh water.

Secondary or tertiary effluent is used to irrigate hundreds of landscape irrigation sites in the United States. The sites include golf courses, parks, school grounds, athletic fields, cemeteries, freeway landscapes, and other open green space.

C. Industrial Reuse

Reclaimed water is of adequate quality for many industrial applications that can tolerate water of less than potable quality, and the reliability of supply is an important advantage. Industries are often located near populated areas that generate large volumes of wastewater. Industrial uses of reclaimed water include cooling, processing, boiler feeding, washing, and transporting material and as an ingredient in a product. Approximately 75% of all industrial water use is for cooling, and cooling is the predominant reuse application, resulting in over 90% of the total volume of industrial reuse.

1. Cooling Water

There are at least 17 steam electric generating plants in the United States that use municipal wastewater as plant makeup water. In general, the major problems unique to power plants employing municipal effluents as makeup water consist of scale formation, corrosion, and biological fouling because of high residual organic substrate and nutrient concentrations in the wastewater. Where the possibility of exposure to aerosols exists, a high degree of disinfection may be required by regulatory agencies to ensure the protection of the neighboring public as well as plant employees.

In most cases, disinfected secondary effluent is supplied to power plants for cooling water, and additional treatment by the industry is often required for recirculating cooling systems. Additional treatment may include lime treatment, alum treatment, ferric chloride precipitation, ion exchange, and reverse osmosis. In some cases, only additional chemical treatment is necessary. Sulfuric acid may be

TABLE XII. Recommended Cooling Water Criteria for Makeup Water to Recirculating System[a]

Parameter	Recommended limit (mg/liter)
Cl	500
TDS	500
Hardness ($CaCO_3$)	650
Alkalinity ($CaCO_3$)	350
pH	**[b]
TSS	100
NH_4	**[b]
SiO_2	50
Al	0.1
Fe	0.5
Mn	0.5
Ca	50
Mg	**[b]
HCO_3	24
SO_4	200

[a]From the National Academy of Sciences–National Academy of Engineering (1973). "Water Quality Criteria 1972." U.S. Environmental Protection Agency, Washington, D.C.
[b]Accepted as received.

added for pH and alkalinity control, polyphosphates for corrosion control, phosphonates or calcium phosphate for destabilization, polyacrylates for suspended solids dispersion, chlorine for biological control, and antifoaming agents for dispersion of foam caused by phosphates and some organic compounds.

The recommended water quality criteria for makeup water to recirculating systems are shown in Table XII. A lower water quality is acceptable for once-through cooling systems.

Advanced treatment, consisting of oxidation, alum coagulation, filtration, and disinfection to a total coliform level of 2.2/100 ml is used for power plant cooling at the City of Burbank, California, power generating plant. The 2 mgd (8000 m^3/d) used for cooling receive additional chemical treatment at the power plant. The City of Glendale, California, receives about 6 mgd (23,000 m^3/d) of similar quality effluent for use in the Glendale Steam Electric Generating Plant. The Nevada Power Company receives unfiltered secondary effluent and provides lime clarification on site for turbidity and phosphorus removal.

The largest industrial reuse application in the United States is at the Bethlehem Steel Corporation's Sparrow Plant in Baltimore County, Maryland, which currently uses approximately 107 mgd (405,000 m^3/d) for cooling and steel production. Reclaimed water uses include roll cooling, descaling, sluicing, gas scrubbing, pickle liquor diluting, slab and coil cooling, and indirect cooling in heat exchangers. Because of the once-through nature of cooling, a relatively low quality secondary effluent from Baltimore's Back River Wastewater Treatment Plant has been successfully used with chlorination being the only additional treatment provided at the plant. The reclaimed water used for other processes at the steel plant receives additional treatment prior to reuse.

2. Boiler Feed Water

The use of reclaimed water for boiler feed water requires extensive additional treatment and is usually not recommended. Quality requirements are dependent on the operating pressure of the boiler and increase directly with the pressure, as indicated in Table XIII. Reclaimed water must be treated to remove hardness. Calcium and magnesium salts are the principal contributors to scale formation and deposits in boilers.

Excessive alkalinity contributes to foaming and results in deposits in heater, reheater, and turbine units. Silica and aluminum form a hard scale on heat-exchanger surfaces, while high concentrations of potassium and sodium can cause excessive foaming in the boiler.

The Wyodak Power Plant in Wyoming reuses 200–300 gpm (13–19 liters/sec) of reclaimed water for boiler makeup, dust suppression, and other small volume plant uses. Both surface water and groundwater sources in the area are inadequate to meet the plant's makeup water needs. Secondary effluent from the city of Gillette is piped approximately 5 miles (8 km) to a sophisticated water treatment system at the power plant. Treatment includes chlorination, softening, activated carbon adsorption, pH adjustment, sand filtration, cartridge filtration, reverse osmosis, dechlorination, recarbonation, and ion exchange demineralization.

3. Process Water

The acceptability of reclaimed water for industrial process water is dependent on the specific application. Whereas relatively low quality secondary effluent may be acceptable for some applications (for example, secondary effluent has been used in the manufacture of concrete), exceptionally high quality water is required for certain industrial applications, for example, washing circuit boards in the electronics industry.

Two paper mills use tertiary treated effluent from the Los Angeles County Sanitation Districts' Po-

TABLE XIII. Recommended Industrial Boiler Feed Quality Criteria[a, b]

Parameter	Low pressure	Intermediate pressure	High pressure
SiO_2	30	10	0.7
Al	5	0.1	0.01
Fe	1	0.3	0.05
Mn	0.3	0.1	0.01
Ca	**[c]	0.4	0.01
Mg	**[c]	0.25	0.01
NH_4	0.1	0.1	0.1
HCO_3	170	120	48
SO_4	**[c]	**[c]	**[c]
Cl	**[c]	**[c]	**[c]
TDS	700	500	200
Cu	0.5	0.05	0.05
Zn	**[c]	0.01	0.01
Hardness ($CaCO_3$)	350	1.0	0.07
Alkalinity ($CaCO_3$)	350	100	40
pH, units	7.0–10.0	8.2–10.0	8.2–9.0
COD	5	5	1.0
H_2S	**[c]	**[c]	**[c]
Dissolved oxygen	2.5	0.007	0.007
Temperature, °F	**[c]	**[c]	**[c]
Suspended solids	10	5	0.5

[a]From the National Academy of Sciences–National Academy of Engineering (1973). "Water Quality Criteria 1972." U.S. Environmental Protection Agency, Washington, D.C.

[b]Recommended limits in mg/liter except for pH and temperature.

[c]Accepted as received.

mona Water Reclamation Plant as process water. The Garden State Paper Company uses 3 mgd (11,000 m^3/d) of reclaimed water during newsprint reprocessing, and the Simpson Paper Company uses 1 mgd (4000 m^3/d) during the manufacture of high-quality paper for stationery and wrappings. The tertiary treatment includes carbon adsorption to remove color from the wastewater.

Industrial reuse is practiced in many countries other than the United States. For example, 32 mgd (120,000 m^3/d) of tertiary treated reclaimed water are used for cooling purposes at 5 power plant facilities in South Africa, and reclaimed water is used in air conditioning systems in several buildings in Japan.

D. Dual Systems

Increasing water demands in urban areas have resulted in the development of several large dual water distribution systems, that is, the distribution of two grades of water to the same service area—one potable and the other nonpotable reclaimed water. A dual water system can provide water for most of the uses listed in Table I. Many of these applications are currently part of dual systems in the United States.

Dual water systems make reclaimed water available throughout a community for irrigation and other uses where significant portions of the population may be exposed to the reclaimed water. Filtered secondary effluent that has been highly disinfected has been proposed by some experts as being appropriate for dual systems providing reclaimed water for diversified uses throughout a community. Maintenance of a chlorine residual throughout a system will prevent the accumulation of bacterial slimes in the distribution system and help maintain a microbiologically safe product water. Chemical constituents in tertiary treated effluent are generally not a problem for most types of nonpotable urban reuse.

While some states have regulations or guidelines for specific types of reuse and for controls during the transportation and distribution of reclaimed water, neither state nor federal standards for reclaimed water distribution via dual systems have been developed.

Among the landmark and better known comprehensive dual distributions systems in the United

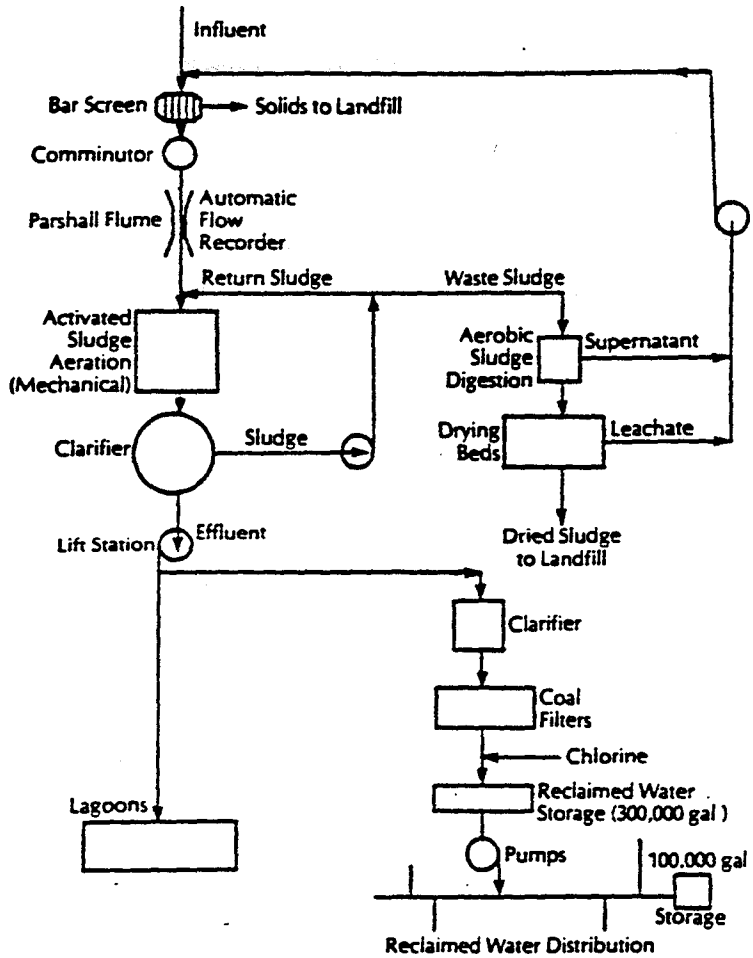

FIG. 3. Schematic of wastewater treatment at Grand Canyon Village, Arizona. [From American Water Works Research Foundation (1978). "Water Reuse Highlights." Denver, Colorado.]

States, where the predominant use of reclaimed water is for irrigation, are

1. *Grand Canyon Village, Arizona:* This represents the oldest dual water system in the United States, begun in 1926. This tourist village on the south rim of the Grand Canyon obtains its drinking water from a spring approximately 0.5 miles (0.8 km) below in the canyon. Approximately 0.03 mgd (110 m^3/d) of filtered activated sludge effluent (see Fig. 3) are used for landscape irrigation, toilet flushing, and construction uses when needed. This is the only dual system in the United States that uses reclaimed water for toilet flushing.

2. *Colorado Springs, Colorado:* In 1960, the city of Colorado Springs initiated the first large-scale reclaimed water dual distribution system in the United States that sold reclaimed water to customers. An extensive nonpotable water distribution system provides reclaimed water to various locations in the city for the irrigation of parks, cemeteries, golf courses, grounds at Colorado College, and other green space and for industrial cooling water. Fire hydrants are located on the pressure lines. Of the 20 mgd (76,000 m^3/d) given secondary treatment, approximately 5 mgd (19,000 m^3/d) receive filtration prior to chlorination and storage in a series of reservoirs.

3. *Irvine Ranch Water District, California:* The 15-mgd (57,000 m^3/d) Michelson Water Reclamation Plant provides advanced wastewater treatment (biological oxidation, chemical coagulation, filtration, and disinfection) and produces an effluent having a total coliform concentration less than 2.2/100 ml. The district reuses all of the wastewater treated at the reclamation plant through an extensive dual distribution system. During wet weather, reclaimed water is stored in surface reservoirs and refiltered to remove algae prior to introduction into the distribution system, while covered tanks are provided for diurnal storage. Beginning with crop irrigation in 1968, the system has been expanded to include ornamental impoundments and the irrigation of parks, golf courses, school grounds, common areas around

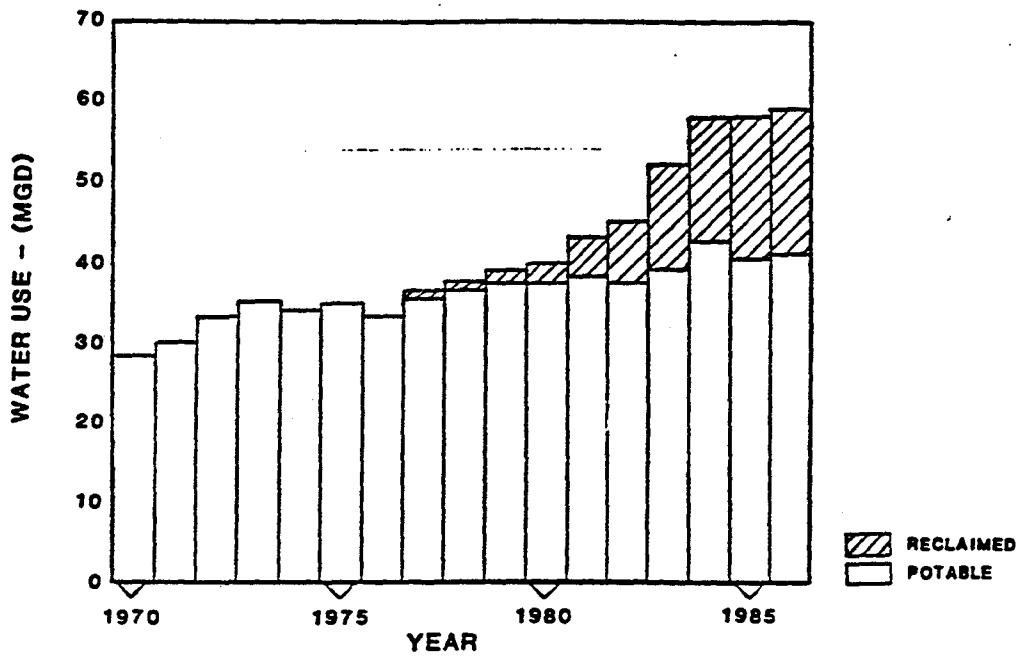

FIG. 4. Potable and reclaimed water use in St. Petersburg, Florida.

condominiums, roadway medians, and other open space. Crops irrigated with reclaimed water include citrus, corn, tomatoes, strawberries, and chili peppers. Reclaimed water for toilet flushing in office buildings is in the process of being introduced.

4. *St. Petersburg, Florida:* Reclaimed water of equivalent quality to that produced by the Irvine Ranch Water District is distributed throughout the city from four treatment plants for irrigation, industrial uses, and fire protection. This dual water system, in operation since 1977 (see Fig. 4), is the largest in the United States and carries 21 mgd (79,000 m^3/d) of irrigation water through 250 miles (400 km) of pipeline ranging in size from 4 to 48 in. (10 to 120 cm) in diameter. In January 1987, the water was used by more than 5200 customers to irrigate 4600 acres (1900 ha) of parks, school grounds, golf courses, and industrial, commercial, and residential neighborhoods. It is estimated that St. Petersburg's reclaimed water system will have the potential to serve approximately 17,000 customers and irrigate almost 9000 acres (3600 ha). Hose bibbs are prohibited, and backflow prevention devices are required on the potable water supply to each irrigation user, including residences. In the absence of state or federal regulations or guidelines, St. Petersburg and the Irvine Ranch Water District pioneered the development of detailed rules, regulations, and design specifications for dual water systems.

All of the above dual water systems—and many other types of reuse systems—incorporate finished water storage facilities into their systems. Storage tanks or reservoirs provide for diurnal variations in demand, provide adequate capacity for fire fighting, if appropriate, and provide for emergency supply in the event of treatment plant failure. Covered storage tanks have the additional benefit of preventing degradation or contamination of the reclaimed water prior to its use. Where seasonal demands vary, excess reclaimed water is often stored in surface reservoirs for use during periods of high demand.

E. Impoundments

Reclaimed water impoundments, which are often used for system or seasonal storage, can be categorized as aesthetic or recreational. Aesthetic impoundments, at which public contact with the reclaimed water is generally prohibited, are typically located in parks, developments, or golf courses where they serve as water hazards. Recreational impoundments can be subdivided into either nonbody contact or body contact impoundments. Nonbody contact includes activities such as boating and fishing where there is incidental contact with the reclaimed water, while body contact impoundments allow full-body immersion. At present, there are no reclaimed water recreational impoundments in the United States that are used for full-body contact activities, although such use is acceptable in some states.

The level of treatment required for the different types of impoundments is generally dependent on the

degree of public contact with the reclaimed water. Recreational impoundments should not contain chemical substances that are toxic on ingestion or irritating to the eyes or skin and should be safe from a microbiological standpoint. Other parameters that may affect acceptability are temperature, pH, chemical composition, aquatic growths, and clarity. Clarity is important for several reasons, including safety, visual appeal, and recreational enjoyment.

Impoundments composed entirely of reclaimed water are prone to eutrophication. The nutrients in the wastewater can cause excessive algae growths and nutrient removal may be necessary. If fish, shellfish, or plants are harvested from reclaimed water for human consumption, both the microbiological and chemical quality of the source water should be thoroughly assessed for possible bioaccumulation of toxic contaminants through the food chain.

The recreational lakes in Santee, California, have been used since 1961 for several activities, limited initially to picnicking and boating and progressing through a "fish for fun" program to a normal fishing program. At Santee, activated sludge effluent is percolated through 400 ft (120 m) of sands and gravel and disinfected prior to discharge to the 5 lakes, which have a surface area of about 30 acres (12 ha). Because of the high nutrient levels in the reclaimed water, there is considerable algal growth in the lakes, which average 1000 ft (300 m) in length and 2–10 ft (0.6–3 m) in depth. Algae control via chemicals or mechanical harvesting is practiced. The lakes have been incorporated into an extensive recreational area widely used by the local populace.

A basin adjacent to one of the lakes was built and used for swimming during the summer of 1965 but was discontinued for economic reasons. The reclaimed water for swimming required the additional treatment of chemical coagulation, filtration, and disinfection for turbidity and iron and manganese control. It was less costly to supply potable water for swimming than to treat reclaimed water.

F. Groundwater Recharge

Groundwater recharge is the planned augmentation of underground water supplies with reclaimed water. The purposes of groundwater recharge are to prevent saltwater intrusion into freshwater aquifers, to store the reclaimed water for future use, to reduce or prevent declines in groundwater levels, to control or prevent ground subsidence, or to augment nonpotable or potable aquifers. It can be accomplished by surface spreading, direct injection, or river bank or stream bed infiltration resulting from stream augmentation.

River bank or stream bed infiltration is not common in the United States, but it is extensively practiced in Europe, where the extracted water is often used as a source of drinking water after treatment by granular activated carbon filters, usually combined with sand filtration and ozonation. With surface spreading, reclaimed water percolates from spreading basins through an unsaturated zone to the groundwater, whereas direct injection entails pumping reclaimed water directly into the groundwater, usually into a confined aquifer. Direct injection is particularly effective in creating saltwater intrusion barriers in coastal areas.

Depending on the reclaimed water characteristics, type of soil, depth of aerobic zone, and spreading area practices, soil percolation may provide additional treatment of the reclaimed water. High levels of microorganisms and some chemical constituents are removed via adsorption, decomposition, precipitation, ion exchange, oxidation, reduction, and other chemical reactions in the upper levels of the soil. Some of these processes retard the rate at which specific chemicals move in the subsurface environment relative to the rate of movement of water. Soils have the capacity to retain large amounts of trace metal elements. It appears that a spreading site can be used for extensive time periods before the soil may become exhausted.

While coarse materials and fracture zones permit the passage of microorganisms into the underground, the concentration of bacteria and parasites in percolating water can be effectively reduced after passage through short distances of the soil mantle via straining, adsorption, and die-off. The primary mechanism of virus removal in the underground is by adsorption to soil particles. Clay soils enhance adsorption. Retention is generally better at lower pH levels and high salt concentrations or with salts having higher cation valences. Virus adsorption is a reversible process and changes in the physical status of a soil, such as pH, ion concentration, or water/soil ratio, can cause desorption of viruses into the percolating water. Virus movement can be reduced by reducing the permeability of a soil. Viruses are capable of traveling considerable distances in the underground, and it is difficult to predict the ability of a soil system to remove viruses.

The level of wastewater treatment provided prior to groundwater recharge may vary depending on the site-specific hydrogeologic conditions, type of recharge, and subsequent use of the extracted groundwater. Direct injection typically requires a high-quality effluent to prevent soil clogging by particulates upon injection, chemical precipitation, or biological growths.

Advanced wastewater treatment may be necessary for the recharge of potable aquifers by either spreading or injection.

Reclaimed water has been used to recharge potable groundwater aquifers by surface spreading since 1962 in Los Angeles County, California. At the present time, 27 mgd (100,000 m^3/d) of highly disinfected filtered secondary effluent from 3 wastewater reclamation plants operated by the County Sanitation Districts of Los Angeles County are spread at Whittier Narrows in the Montebello Forebay area of Los Angeles County. Reclaimed water accounts for approximately 20% of the inflow into the basin.

A 5-yr health effects study was initiated in 1978 to determine whether the Whittier Narrows groundwater recharge project had an adverse effect on the groundwater or the health of individuals ingesting the groundwater. The study included extensive microbiological and chemical water quality characterizations, percolation studies, toxicological studies, and epidemiological studies. The reclaimed water and groundwater complied with all federally prescribed drinking water standards, and no pathogenic organisms were detected in either the reclaimed water or groundwater. Water quality data for reclaimed water and well water are given in Tables XIV and XV. The Whittier Narrows study did not demonstrate any measurable adverse effects on the area's groundwater or the health of the population ingesting the water. The epidemiological study findings are somewhat weakened by the fact that the minimal observed latency period for human cancers that have been

TABLE XIV. Average Water Quality of Reclaimed Water Used for Groundwater Recharge at Whittier Narrows[a]

Constituent	Reclaimed water[b]	Groundwater[b]
Turbidity, NTU	0.8	1.1
Color, CU	22.5	<5
pH, Units	7.23	7.65
Dissolved solids	568	475
Total alkalinity	220	178
Chloride	133	61
Sulfate	113	130
Nitrate	0.34	2.06
Nitrite	0.40	<0.01
Ammonia	13.7	0.1
Phosphate	10.6	0.5
Fluoride	0.65	0.41
Cyanide	<0.01	<0.01
Hardness ($CaCO_3$)	194	274
Arsenic	0.003	0.004
Barium	0.22	0.32
Cadmium	<0.002	0.002
Chromium	<0.01	<0.01
Copper	0.008	<0.007
Iron	<0.06	0.25
Lead	<0.02	<0.02
Manganese	<0.01	<0.04
Mercury	<0.001	<0.001
Nickel	0.05	<0.02
Selenium	<0.003	<0.003
Silver	0.001	<0.002
Sodium	105	58
Zinc	0.03	0.03
TOC	11.2	1.0
Bromide	<0.30	0.20
Total coliform, MPN/100 ml	8	<2
Fecal coliform, MPN/100 ml	<2	<2

[a]From Nellor, M. H., Baird, R. B., and Smyth, J. R. (1984). "Health Effects Study Final Report." County Sanitation Districts of Los Angeles County, Whittier, California.

[b]Reported in mg/liter unless otherwise noted.

TABLE XV. Results of Organic Analyses of Reclaimed Water and Well Water at Whittier Narrows[a]

Compound	Reclaimed water[b] (μg/liter)	Chlorinated well water (μg/liter)
Methylene chloride	4.9–56	<0.2–1.8
Chloroform	5.8–84	<0.1–1.6
Bromodichloromethane	<0.1–2.9	<0.1–9.1
Dibromochloromethane	<0.1–2.1	<0.1–43
Bromoform	<0.1–4.8	<0.1–50
Carbon tetrachloride	<0.1–12	<0.1
1,1-Dichloroethane	<0.1–1.8	<0.1–0.4
1,2-Dichloroethane	<0.2–2.2	<0.2
1,1,2-Trichloroethane	<0.2–21	<0.2
Trichloroethylene	<0.1–19.4	<0.1–0.4
Tetrachloroethylene	<0.1–17.4	<0.1–0.5
Chlorobenzene	<0.1–1.0	<0.1
1,4-Dichlorobenzene	0.2–10.2	<0.2–0.4
1,2-Dichlorobenzene	0.2–6.0	<0.2–0.6
Benzene	<0.2–2.9	<0.2–0.3
Toluene	<0.1–1.3	<0.1–0.2
Bis(2-ethylhexyl)phthalate	0.7–13	<0.5–5.7
1,2,4-Trichlorobenzene	<0.1	<0.1
2,4,6-Trichlorophenol	<0.2–0.7	<0.2
2,4,5-Trichlorophenol	<0.2–0.9	<0.2
2,3,4-Trichlorophenol	<0.4	<0.4
2,3,6-Trichlorophenol	<0.2	<0.2
3,4,5-Trichlorophenol	<0.9	<0.9
Pentachlorophenol	<1.3–16	<1.3
Lindane	<0.2–1.0	<0.2
2,3′,5-Trichlorobiphenyl	<0.1–0.7	<0.1
2,2′,4,4′-Tetrachlorobiphenyl	<0.2	<0.2
Aldrin	<0.2–0.9	<0.2
Phenanthrene	<0.2–1.7	<0.2
Fluoranthene	<0.2	<0.2
DDT	<0.2	<0.2
Dieldrin	<0.4	<0.4
Atrazine	<0.5	<0.5–0.9
Simazine	<1.1	<1.1–1.7
Phenylacetic acid	<0.7	**[c]

[a]From Nellor, M. H., Baird, R. B., and Smyth, J. R. (1984). "Health Effects Study Final Report." County Sanitation Districts of Los Angeles County, Whittier, California.
[b]Oxidized, filtered, disinfected effluent.
[c]Compound was detected but could not be quantified.

linked to chemical agents is about 15 yr, and may be much longer. Because of the relatively short time period that groundwater containing reclaimed water has been consumed, it is unlikely that examination of cancer mortality rates would have detected an effect, if present, of exposure to reclaimed water resulting from the groundwater recharge operation.

A scientific advisory panel on groundwater recharge, established by the state of California in 1986, concurred with the Whittier Narrows health effects study findings and concluded that the risks associated with this project were small and probably not dissimilar from those that could be hypothesized for commonly used surface water. Based on the health effects study and the scientific advisory panel's conclusions, the regulatory agencies have approved expansion of the groundwater recharge operation to a maximum of 45 mgd (170,000 m^3/d).

Reclaimed water produced at the Orange County Water District's Water Factory 21 in Fountain Valley, California, is injected into a series of 23 multicasing injection wells, similar to that shown in Fig. 5, pro-

viding 81 individual injection points to form a seawater intrusion barrier. As indicated in Fig. 6, the 15-mgd (57,000 m^3/d) facility, which has been in operation since 1976, includes several advanced wastewater treatment processes. Because of a total dissolved solids limitation of 500 mg/liter prior to injection, reverse osmosis is used to demineralize 5 mgd (19,000 m^3/d) of the wastewater used for injection. The product water is blended 50:50 with deep well water prior to injection. Once underground, some of the injected water flows toward the ocean forming a seawater barrier, but the majority of the water flows inland to augment the potable groundwater supply.

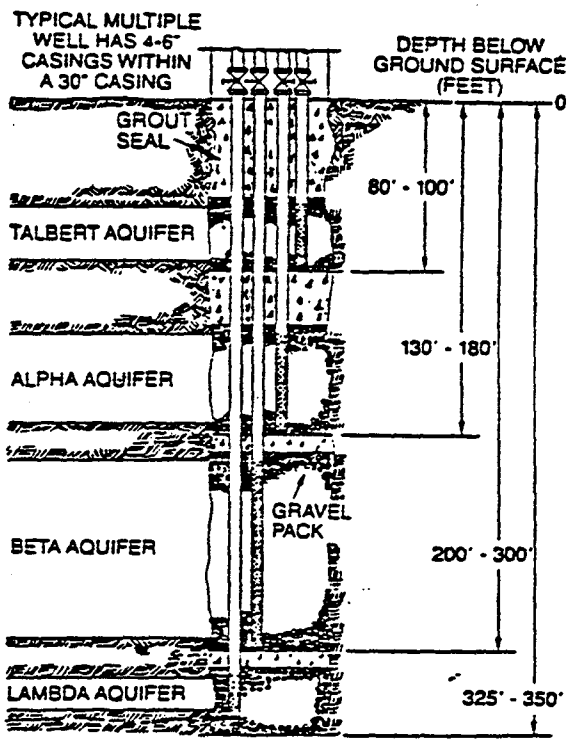

FIG. 5. Typical multicasing injection well for Water Factory 21 effluent.

A prototype direct injection project has been in operation in El Paso, Texas, since 1985, supplying more than 5 mgd (19,000 m^3/d) of highly treated reclaimed water to the underground via ten 800-ft (250-m) deep recharge wells. Ultimately, the treated wastewater returns to the city's potable water system. While the reclaimed water currently recharged represents a small percentage of the total aquifer volume, the long-term goal is to provide 25% of El Paso's future water needs with reclaimed water.

G. Direct Potable Reuse

While it may be technically possible to produce reclaimed water of almost any desired quality, health authorities have been reluctant to allow or support direct potable reuse and generally subscribe to the concept of using natural waters derived from the most protected source as raw water supplies rather than wastewater known to contain a myriad of harmful chemical and microbiological constituents. Public health issues notwithstanding, direct potable reuse is receiving increasing attention in the United States and elsewhere.

The only planned direct potable reuse operation in the world is at Windhoek, Namibia. Potable reuse was initiated in 1969 from a 1.2-mgd (4,500 m^3/d) potable reuse plant and up to one-third of the city's water supply has been made up of reclaimed water. The decision to build the plant was precipitated by severe water shortages and the absence of alter-

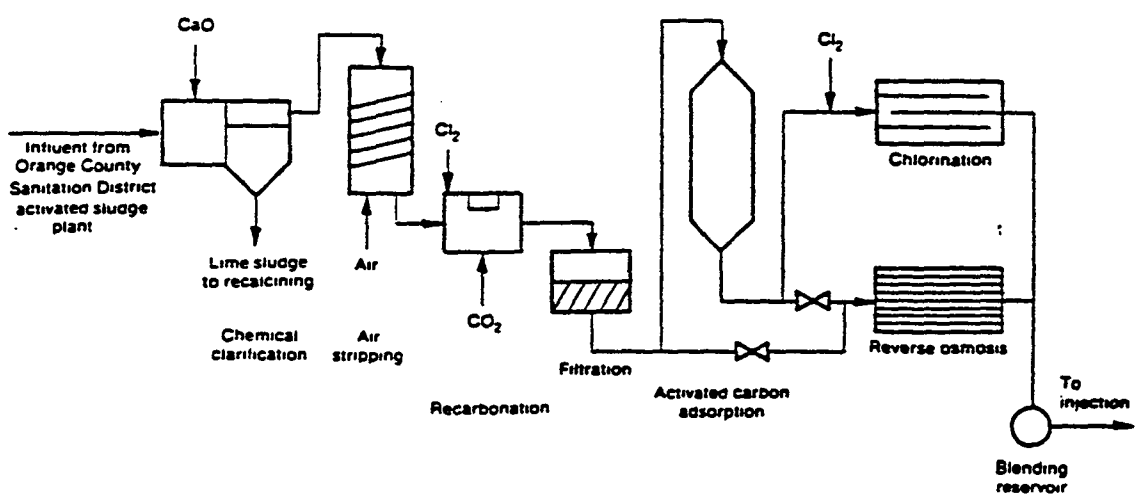

FIG. 6. Wastewater reclamation unit processes at Water Factory 21, Orange County, California. [From Ridgway, H. F., Rigby, M. G., and Argo, D. G. (1985). Bacterial adhesion and fouling of RO membranes. *J. Am. Water Works Assoc.* 77 (7), 97.]

native sources of supply at that time. Although alternative sources have since been developed, the plant is being operated on an intermittent basis, according to need. Modifications and improvements to the reclamation plant and upgrading the preceding biological treatment system, which has wastewater devoid of toxic industrial wastes, have been made over the years. Current treatment processes include maturation ponds, chemical coagulation, ammonia stripping, recarbonation, sand filtration, breakpoint chlorination, carbon adsorption, and final chlorination. Excessive buildup of TDS is limited by the high consumptive water use in the area, and desalting is unnecessary.

Evaluation of treatment technology for direct potable reuse is continuing at several facilities in South Africa, including the Stander demonstration plant in Pretoria, the Athlone experimental plant in Cape Town, and the Cape Flats demonstration plant, and at the Windhoek plant. In the United States, research directed at the reuse of wastewater for potable purposes is being conducted in Denver, Colorado; San Diego, California; and Tampa, Florida.

H. Environmental Enhancement and Other Reuse

Reclaimed water is used for several types of environmental enhancement, some of which are commonly associated with wastewater disposal. There are several examples of reclaimed water discharged to—or used to create—marshes, wetlands, or aquatic wildlife habitats. San Diego County, California, is evaluating a "live stream concept" in which reclaimed water would be discharged to streams for the purpose of maintaining a constant high-quality flow of water to enhance the aquatic and wildlife habitat and maintain the aesthetic value of the watercourses. Effluent discharged into these systems receives the benefit of additional treatment by natural purification processes.

Utilizing reclaimed water for commercial fish production ponds is practiced in Israel and is widespread in China. Bioaccumulation of metals and organic constituents in fish and other aquatic organisms has been observed. Large-scale fish production with reclaimed water is being investigated in the United States and could present a significant future use.

Other current uses include livestock water; frost protection of crops; construction applications, such as soil compaction and dust control; log wetting at pulp and paper mills; fire protection; equipment washdown; and toilet flushing. At least 25 individual on-site wastewater treatment systems in the United States provide reclaimed water for toilet and urinal flushing in office buildings, schools, shopping centers, and manufacturing plants. An on-site wastewater treatment and recycling system is shown in Fig. 7. There are approximately 50 on-site systems in Japan providing reclaimed water for toilet flushing in commercial buildings, schools, hospitals, hotels, and a large apartment complex. Making snow at ski

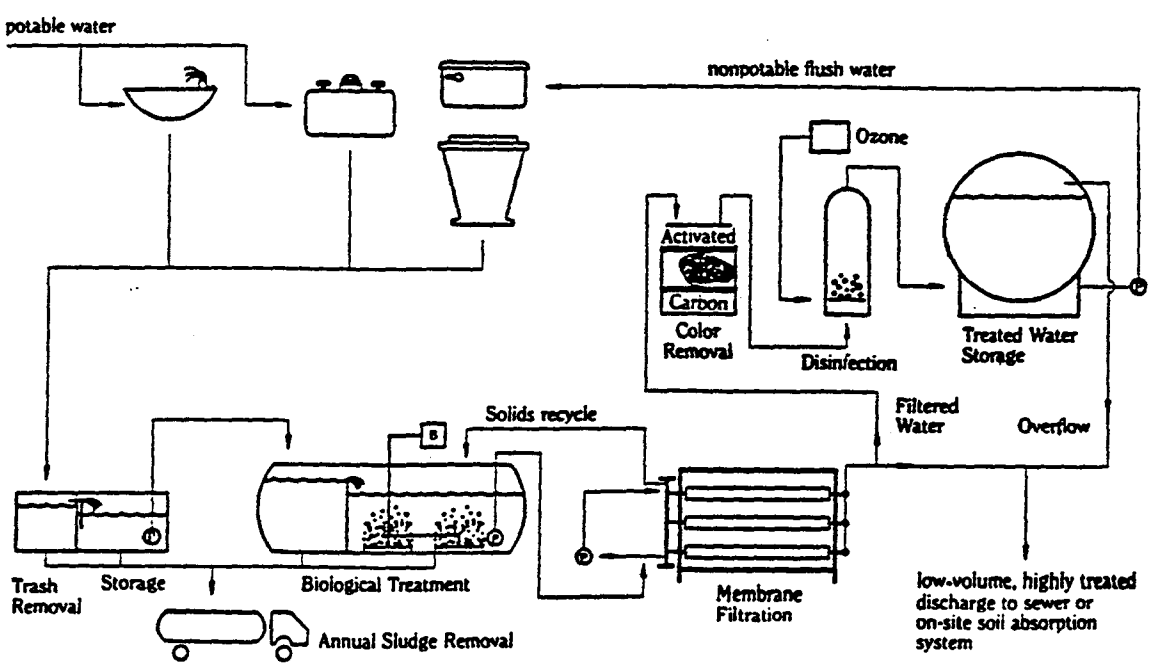

Fig. 7. Cycle-let on-site wastewater treatment and recycling system. [Courtesy of Thetford Systems, Inc., Ann Arbor, Michigan.]

resorts, washing vehicles, using in washing machines at laundromats, and cleaning streets and using it as process water at food processing plants are some of the uses for which reclaimed water has been considered.

VI. Reuse Standards and Guidelines

Standards for the reuse of wastewater are principally directed at public health protection and are generally based on the control of pathogenic organisms and, in some cases, on the control of chemical constituents of health concern. Most microbiological standards are based on the use of coliform bacteria as indicator organisms to determine the reclaimed water quality. The identification and enumeration of viruses in wastewater are hampered by the lack of standardized sampling and analytical procedures, relatively low virus recovery rates, the complexity and high cost of laboratory procedures, and the limited number of facilities having the personnel and equipment necessary to perform the analyses. Furthermore, the laboratory culturing procedure to determine the presence or absence of viruses in a water sample takes about 14 days, and another 14 days are required to type (identify) the viruses.

Standards governing the quality of wastewater used for irrigation purposes have existed for many years in several countries. In Germany, biological treatment and chlorination are required for the irrigation of pasture. Irrigation of crops for human consumption that will be processed to kill pathogens must cease at least 4 weeks prior to harvesting. Potatoes and cereals are the only nonprocessed crops for which reclaimed water may be used for irrigation, and irrigation is allowed through the flowering stage only. In South Africa, heavily chlorinated tertiary effluent is required for the irrigation of orchards and vineyards, fodder crops, and processed food crops. In contrast, regulations in Israel allow the use of secondary effluent on orchards, vineyards, and fodder crops, and disinfected wastewater (less than 1000 coliforms/100 ml in 80% of the samples) for processed food crops. The only nonprocessed food crops that can be irrigated with reclaimed water are fruits that are peeled before eating. In 1971, the World Health Organization (WHO) sponsored a meeting of experts on the reuse of effluents and subsequently published a technical report suggesting treatment processes to meet health criteria for various types of wastewater reuse. The WHO's recommendations ranged from primary treatment for the irrigation of food crops not for direct human consumption to advanced treatment including filtration, nitrification, disinfection, and possibly denitrification, chemical clarification, carbon adsorption, and ion exchange for potable reuse.

In 1986, a meeting of scientists and epidemiologists was held in Engelberg, Switzerland to discuss the health risks associated with wastewater irrigation. It was concluded at that meeting, sponsored by WHO and the World Bank, that the health risks of irrigation with well-treated wastewater were minimal and that current bacterial standards were unjustifiably restrictive. It was recognized that in many developing countries the main risks were associated with helminth diseases and that safe use of wastewater would require a high degree of helminth removal. A microbial standard of 1000 fecal coliform organisms/100 ml for unrestricted crop irrigation was suggested as being both epidemiologically sound and technologically feasible in developing countries.

There are no federal standards governing wastewater reuse in the United States, and the regulations that do exist are developed at the state level. Eleven states have published standards or guidelines for one or more types of wastewater reuse. Some states require specific treatment processes, other states impose effluent quality requirements, and some states require both. All of the 11 states require disinfection for most uses and limits for either total or fecal coliform organisms. Standards for industrial reuse are developed and implemented on a case-by-case basis. Fourteen states permit wastewater reuse but do not have specific published criteria. The remaining 25 states either prohibit or discourage wastewater reuse.

The two states having the most comprehensive and among the most stringent wastewater reclamation regulations are Arizona and California. The Arizona regulations impose water quality requirements and significant monitoring requirements for various pathogens, including viruses. The regulations include permit requirements and use area requirements. The California wastewater reclamation criteria are summarized in Table XVI and include both treatment and water quality requirements.

The California regulations also include requirements for treatment reliability. The reliability requirements address alarm systems, standby power supplies, multiple or standby units, emergency storage or disposal of inadequately treated wastewater, elimination of treatment process bypassing, monitoring devices and automatic controllers, and flexibility of design.

No state has developed regulations for direct po-

TABLE XVI. California Treatment and Quality Criteria for Reuse

Type of use	Coliform limits	Treatment required
Fodder, fiber, and seed crops; surface irrigation of orchards and vineyards		Primary
Pasture for milking animals, landscape impoundments, landscape irrigation (golf courses, cemeteries, etc.)	23/100 ml	Oxidation and disinfection
Surface irrigation of food crops, restricted recreational impoundments	2.2/100 ml	Oxidation and disinfection
Spray irrigation of food crops, landscape irrigation (parks, playgrounds, etc.) Nonrestricted recreational impoundments	2.2/100 ml	Oxidation, coagulation, clarification, filtration[a], and, disinfection

[a]The turbidity of filtered effluent cannot exceed an average of 2 turbidity units during any 24-hr period.

table reuse and some states explicitly prohibit the direct potable reuse of reclaimed wastewater. California's wastewater reclamation criteria include general requirements for indirect potable reuse via groundwater recharge by surface spreading. The regulations state that "reclaimed water used for groundwater recharge by surface spreading shall be at all times of a quality that protects public health" and that "the State Department of Health Services recommendations to the Regional Water Quality Control Boards will be based on all relevant aspects of each project, including the following factors: treatment provided; effluent quality and quantity; spreading area operations; soil characteristics; hydrogeology; residence time; and distance to withdrawal." More specific groundwater recharge criteria are being developed that will address these factors.

Water reuse requirements have recently been developed in Florida. Florida's irrigation requirements depend upon the extent of public access to the site, the level of operational management, the location relative to groundwater and surface water, and other factors. For the irrigation of areas with restricted public access and crops not intended for human consumption, secondary treatment and disinfection to achieve an effluent fecal coliform level not exceeding 200 organisms/100 ml is required. For food crop irrigation and the irrigation of areas accessible to the public, such as golf courses, parks, and cemeteries, secondary treatment followed by filtration and disinfection is required with water quality limitations of 5 mg/1 TSS and no detectable fecal coliforms.

Several states impose design and operational controls over the distribution and use of reclaimed water, often on a case-by-case basis. Requirements may include cross-connection control provisions, on-site monitoring, prevention of public contact with the reclaimed water, public notification, contracts between reclaimed water producers and users, control of runoff or ultimate disposal, and provisions for worker protection.

VII. Public Policy

There have been several major studies in the United States during the 1970s and 1980s that assessed public acceptance of reclaimed water using probability sampling techniques to evaluate attitudes. Twenty-five uses of reclaimed water have been ranked in Table XVII according to the weighted mean of percentages of unfavorable responses from several studies. The results of the different studies are quite consistent, for example, the range was from 44 to 60% of negative, opposed, or unfavorably disposed to the use of reclaimed water for drinking. The data indicate that unfavorability toward reuse of reclaimed water varies directly with intimacy or degree of human contact with the water.

Demographic factors are related to attitudes. In general, younger, highly educated, affluent people are more favorable to reuse than older, poorly educated, or less affluent people. Men favor intimate uses of reclaimed water more than women. Other factors likely to increase public acceptance include awareness of local water problems and need for water, perception of reclaimed water as a resource, confidence in modern technology, and assurance of minimal health risks and economical benefits associated with reuse.

The main legal factors associated with reuse are water rights (both surface water and groundwater), regulations, and liability. The issue of water rights is

TABLE XVII. Public Opposition to Various Uses of Reclaimed Water

Type of reuse	Percent opposed
Food preparation in restaurants	56
Drinking water	54
Cooking in the home	48
Preparation of canned vegetables	46
Bathing in the house	33
Pumping down special wells	27
Home laundry	23
Swimming	21
Commercial laundry	19
Spreading on sandy areas	16
Irrigation of dairy pasture	14
Irrigation of vegetable crops	13
Vineyard irrigation	13
Orchard irrigation	10
Pleasure boating	10
Hay or alfalfa irrigation	8
Commercial air conditioning	7
Golf course hazard lakes	6
Electronic plant process water	5
Home toilet flushing	4
Residential lawn irrigation	4
Irrigation of recreational parks	3
Golf course irrigation	3
Irrigation of freeway greenbelts	2
Road construction	2

[a]From Bruvold, W. H. (1987). Public evaluation of salient water reuse options. *Proc. Water Reuse Symp., 4th, 1987.* American Water Works Association Research Foundation, Denver, Colorado.

very complex and differs among regions and states. The two major doctrines governing surface water are prior appropriation and riparian rights. The prior appropriation doctrine is mainly used in the western United States. This doctrine essentially states first in time, first in right; unclaimed water rights in a surface water can be claimed by anyone as long as the water is put to beneficial use. In most states, water rights can be transferred freely under this doctrine. The riparian rights doctrine allows the owner of property contiguous to a surface water the right to use the water flowing past the property, unimpaired in quality and undiminished in quantity by upstream owners except for natural and domestic uses. The owner may make reasonable use of the water, which may result in some reasonable diminution of quality and quantity.

There are three principal doctrines governing groundwater rights. The first doctrine is absolute ownership, in which the owner's property extends to the center of the earth. This allows the property owner unlimited extraction of groundwater as long as the water is used for a beneficial purpose. The second doctrine is the reasonable use rule, which limits the property owner's groundwater use to the quantity necessary to sustain his or her land. A third doctrine is the correlative rights rule, which provides for the sharing of water among the landowners over a common aquifer.

Product liability laws are intended to encourage the manufacturer, supplier, or seller to provide products that are safe and not defective by shifting the economic cost of injury away from the injured party. The types of liabilities that potentially apply to a water reuse project are personal or property injury, injury resulting from intentional or unintentional acts, damage to and disruption of product quality and quantity, default of express or implied warrant, and breach of contract. The liabilities accepted by the reclaimed water producer, supplier, and user are usually identified in contractual agreements between the involved parties.

The regulatory requirements related to reuse are highly variable for different states. Federal, state, and local agencies involved in wastewater reuse include state and local health agencies, state and regional water resources and water pollution agencies, public utility commissions, state and federal environmental protection agencies, and several permitting authorities.

Institutional factors are those that are not technical in nature, but affect project implementation. Examples of institutional factors include health regulations, economics, urban growth, neighborhood opposition, and agency conflicts. Regulatory attitudes toward reuse tend to be more restrictive in the United States than in many other parts of the world. The difficulties associated with risk assessment, as applied to wastewater reuse, are quantifying the risks involved and obtaining agreement regarding the level of risk to accept.

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Health and Water-Quality Considerations with a Dual Water System

In 1977, the city of St. Petersburg, Fla., initiated an urban dual water distribution system using reclaimed municipal wastewater as the secondary supply source. In 1987, in response to the absence of definitive water reclamation criteria, St. Petersburg officials commissioned a panel of engineering and public health experts to prepare a white paper, "Urban Water Reuse in the City of St. Petersburg: Water Quality and Public Health Considerations."

The panel concluded that no evidence exists of increased enteric diseases in urban areas irrigated with treated reclaimed wastewater using coagulation, filtration, and disinfection.

Evidence does not indicate significant risks of transmission of viral or microbial diseases as a result of exposure to effluent aerosols from spray irrigation with reclaimed water.

The panel recommended that wastewater treatment systems discharging into a reclaimed water system be designed, constructed, operated, and monitored in the most responsible manner possible to ensure public health and safety. Other recommendations included a Class I advanced secondary treatment facility that handles projected hydraulic and organic loadings and allows chemical addition before filtration. In addition, 24 h/d, 7 d/wk effluent sampling and 24 h/d, 7 d/wk surveillance by qualified operators were recommended as standard facility practices.

The panel also recommended a turbidity standard averaging 2.0 NTU during any 24-hour period. The system should provide continuous, on-line turbidity monitoring. The standard for fecal coliform was recommended as an average of 2.2/100 mL with an upper limit of 23/100 mL in not more than 10% of the samples, while maintaining a 4.0-mg/L chlorine residual. Virus standards for reclaimed water were not recommended. The panel concluded that other surrogate parameters efficiently eliminated viruses. However, periodic virus monitoring was recommended to build public confidence in the reclaimed water product.

In addition to compliance monitoring at the wastewater treatment plant, the panel recommended monitoring the distribution system to guard against bacterial regrowth and to ensure an aesthetic product.

Although not required to do so, St. Petersburg embarked quickly on a program to conform to the panel's recommendations to ensure adequate health protection in the areas using reclaimed water.

In 1989, the Florida Department of Environmental Regulation adopted comprehensive water reclamation regulations, including treatment and quality criteria. For residential and public access area irrigation, the regulations require that the wastewater receive secondary treatment, filtration, and disinfection to reduce the fecal coliform level below detectable limits 75% of the time and to prevent the level from exceeding 25/100 mL at any time. The regulations also specify a maximum biochemical oxygen demand (BOD) limit of 20 mg/L, a total suspended solids limit of 5 mg/L before disinfection, and continuous monitoring and recording of turbidity and chlorine residual.

Residual Irrigation

Residual landscape irrigation with reclaimed water is voluntary in St. Petersburg. Reclaimed water lines are brought into an area when at least 50% of the residents in that area petition for service and agree to connect to the reclaimed water system. The residents who hook up to the reclaimed water system pay the cost of extending the distribution lines to serve them, which typically ranges from $500 to $1200 per customer. The total connection charge for a 5/8 or 3/4-in. line is $295—a $180 tapping fee and $115 for a backflow prevention device on the potable water line. Reclaimed water costs $10.36 for the first 0.4 ha (1 ac) and $5.92 for each additional 0.4 ha (1 ac) or portion thereof.

QUALITY OF RECLAIMED WATER

The city's water reclamation system—one of the largest of its kind in the world—currently supplies approximately 76×10^3 m^3/d (20 mgd) of reclaimed water to more than 7000 customers. St. Petersburg has four water reclamation plants (WRPs): Albert Whitted (Southeast) WRP; Northeast WRP; Northwest WRP; and Southwest WRP. The plants have treatment capacities ranging from 47×10^3 m^3 (12.4 mgd) to 76×10^3 m^3/d (20 mgd), with a total rated capacity of 260×10^3 m^3/d (68.4 mgd). The treatment process at all of the plants consists of grit removal, activated sludge biological treatment, secondary clarification, coagulant addition, filtration, and disinfection. Covered storage of the reclaimed water is provided at each of the WRPs. The reclaimed water ground storage tanks have a total capacity of 95×10^3 m^3 (25 mil. gal).

Reclaimed water is delivered through more than 139 km (80 mi) of trunk and transmission lines ranging from 25 cm (10 in.) to 20 cm (48 in.) in diameter. Local service is provided through more than 260 km (160 mi) of small-diameter distribution pipe ranging from 5 cm (2 in.) to 20 cm (8 in.) in diameter. In 1989, approximately 64×10^3 m^3/d (17 mgd)—40% of the total flow—of reclaimed water was used by system customers to irrigate more than 2000 ha (5000 ac) of parks, school grounds, golf courses, and industrial, commercial, and residential neighborhoods. The reclaimed water is also used for cooling at a resource recovery facility and in air conditioning units at commercial buildings, including the recently completed Suncoast Dome sports stadium.

Effluent that does not meet water-quality requirements and that is not used in the plant is disposed of in deep injection wells. The wells penetrate to a saltwater aquifer approximately 300 m (1000 ft) below land surface. Two or three injection wells are located at each of the plants. Injection capacity is approximately 530×10^3 m^3/d (140 mgd).

The city uses two key parameters for instant evaluation of water quality and acceptability for reuse: turbidity and chlorine residual. Effluent having a turbidity of 2.5 NTU or greater or a chlorine residual of less than 4.0 mg/L is discharged to the injection wells, as is effluent having chloride or total suspended solids levels above 600 mg/L and 5 mg/L, respectively.

A typical residence in St. Petersburg may need as much as 98 m^3 (26,000 gal) per month of reclaimed water for landscape irrigation during peak demand periods, assuming a residential lot size of 650 m^2 (7000 ft^2) and an irrigation rate of 4 cm/wk (1.5 in./wk). The average home discharges approximately 23 m^3/mo (6000 gal/mo) of sewage into the sanitary sewer system. Thus, it may require

more than four sanitary sewer customers to provide an adequate supply to one reclaimed water customer during peak demand periods. Reclaimed water use for residential irrigation in St. Petersburg is not metered and surveys indicate that most residential customers use about 20% more reclaimed water than necessary for proper irrigation. Irrigation rates in excess of 4 cm/wk (1.5 in./wk) can increase weed infestations and fungal diseases in many turf grass species.

Use of the nutrient-rich reclaimed water has resulted in reduced fertilizer costs for the system's irrigation customers. Application of approximately 4 cm/wk (1.5 in./wk) of reclaimed water provide approximately 50% of the nitrogen, phosphorus, and potassium requirements for horticultural and agricultural purposes.

There have not been any reported cases of illness or disease resulting from the use of reclaimed water in St. Petersburg. This is particularly significant because many residents are elderly and thus more susceptible to disease than the general population.

Data from 1980 to 1985 were reported to the Centers for Disease Control for two enteric viruses—aseptic meningitis and hepatitis A—historically associated with waterborne disease transmission. These data gave no indication that the use of reclaimed water in St. Petersburg altered the expected epidemiological patterns of these diseases in Pinellas County, in which St. Petersburg is located. The reported incidence rate of aseptic meningitis in Pinellas County was not significantly different from the national rate for the same period, while the hepatitis A incidence rate in Pinellas County was below the national rate.

From 1981 to 1988, more than 200 reclaimed water samples were analyzed for viruses. Detectable levels of viruses were occasionally observed, mostly when the wastewater did not meet treatment or quality criteria and thus was not reused. Improvements in treatment and reliability at the WRPs during the time they have been operating has greatly reduced the number of samples having detectable levels of viruses. The few samples that were positive contained less than 1 enteric virus/100 L.

SYSTEM PROBLEMS

Degradation of finished water. In the early stages of the reclaimed water program, reclaimed water was stored in an open pond at the Southwest WRP before pumping to the distribution system. Unfortunately, the turnover rate of reclaimed water in the pond was low, and the nutrients in the water promoted duckweed and algal blooms. In addition, palm tree seeds dropped into the pond by birds, and other particulates, caused considerable clogging of the irrigation spray nozzles.

These problems occurred at a time when the Northeast WRP was undergoing renovation, including construction of a storage pond. The pond construction was halted and a covered ground storage tank was installed. A covered ground storage tank has replaced the pond at the Southwest WRP. All of the storage facilities at the four WRPs are now covered ground storage tanks.

High chlorides. In 1985, St. Petersburg received complaints from some residential homeowners that irrigation with reclaimed water caused damage to ornamental plants and trees. In response, a research study, "Project Greenleaf," was initiated to determine the effects of irrigating with reclaimed water on commonly used ornamental plants and trees. The study determined that chloride levels of above 400 mg/L in irrigation water for an extended time can damage salt-sensitive plant species. A total of 205 common ornamental plant species were evaluated for their tolerance to chloride, and it was found that three species of plants—crepe myrtle, azalea, and Chinese privet—have extremely low salt tolerances and should not be irrigated with reclaimed water.

It is likely that plant damage was caused by reclaimed water from the Northwest WRP. Chloride levels in the reclaimed water doubled when the sewer systems from the coastal island communities of St. Petersburg Beach and Treasure Island were connected to the Northwest WRP system. In 1985 and 1986, chloride concentrations also increased because of prolonged drought, and peaks of 700 mg/L were recorded. Continuous infiltration of seawater into the communities' sewers, combined with the drought that reduced the volume of freshwater normally infiltrating into the system during the wet period, resulted in an increased concentration of chlorides in the influent.

Mixing reclaimed water from the Northwest WRP with reclaimed water from one or more of the other reclamation plants would have reduced the chloride concentration to an acceptable level. However, this was not possible because the reclaimed water system did not have the flexibility to induce mixing. Instead, the Northwest WTP effluent chloride levels were closely monitored and, when chloride levels were high, the entire effluent was diverted to the injection wells. Customer complaints ceased when chloride levels dropped below 400 mg/L in 1987.

Instrumentation. As the reclaimed water system has evolved into a large-scale integrated network through the years, system operators have become aware of the need for instrumentation enhancements to provide better operational control and management of the overall system. Improved instrumentation is currently being designed into the system and is scheduled for completion in 1992. It will include upgraded monitoring capability for several water-quality parameters at the reclamation plants, remote system monitoring at several locations for pressure and flow, a centralized data monitoring and recording capability, and a system hydraulic model to aid in both short-term operational decisions and longer-term planning decisions.

Inadequate supply. Although on a yearly average basis about 60% of the effluent is injected into the deep wells, there are times when the demand can exceed the supply. Reclaimed water demands increase substantially during the hot, dry spring months when wastewater flows are at a minimum because of lowered groundwater levels that reduce infiltration into the gravity sewer system. Single and consecutive day peak demands stress the system. On several occasions during the last 3 years, some areas served by the system have experienced very low reclaimed water pressure for short time periods.

The city is evaluating the need for additional storage to help alleviate this problem. Other measures under consideration include metering the reclaimed water to control overuse, restricting irrigation during critical periods, and restricting further expansion of the reclaimed water system.

*—**James Crook**, Camp Dresser & McKee, Clearwater, Fla., and **William D. Johnson**, Public Utilities Department, St. Petersburg, Fla.*

Nature Loves Ice Cream (Wastes)

In 1978, Ben & Jerry's Homemade Ice Cream exploded onto the ice cream scene with a kaleidoscope of zany colors and flavors, including Cherry Garcia—(named after Jerry Garcia, lead singer of The Grateful Dead)—and Chunky Monkey, which is filled with bananas.

Today, the ice cream company, based in Waterbury, Vt., is blazing other new trails with a comprehensive environmental program including complete paper recycling, a public education program that includes a promotional bus called the Vaudeville Light Circus Bus, and an experimental aquatic wastewater treatment system that treats ice cream wastes.

WASTEWATER TREATMENT PROGRAM

The aquatic wastewater treatment system consists of solar-silos, which remove biological oxygen demand (BOD) and suspended solids, and constructed marshes,

Water Pollution Control Federation®

Groundwater Recharge with Reclaimed Water in California

James Crook, Takashi Asano, Margaret Nellor

In California, increasing demands for water have given rise to surface water development and large-scale projects for water importation. Economic and environmental concerns associated with these projects have expanded interest in reclaiming municipal wastewater to supplement existing water supplies. Groundwater recharge represents a large potential use of reclaimed water in the state. For example, several projects have been identified in the Los Angeles area that could use up to 150 x 10^6 m^3/a (120,000 ac-ft/yr) of reclaimed water for groundwater recharge. Recharging groundwater with reclaimed wastewater has several purposes: to prevent saltwater intrusion into freshwater aquifers, to store the reclaimed water for future use, to control or prevent ground subsidence, and to augment nonpotable or potable groundwater aquifers.[1] Recharge can be accomplished by surface spreading or direct injection.

With surface spreading, reclaimed water percolates from spreading basins through an unsaturated zone to the groundwater. Direct injection entails pumping reclaimed water directly into the groundwater, usually into a confined aquifer. In coastal areas, direct injection effectively creates barriers that prevent saltwater intrusion. In other areas, direct injection may be preferred where groundwater is deep or where the topography or existing land use makes surface spreading impractical or too expensive. While only two large-scale, planned operations for groundwater recharge are using reclaimed water in California, incidental or unplanned recharge is widespread.

The constraints of groundwater recharge with reclaimed water include water quality, the potential for health hazards, economic feasibility, physical limitations, legal restrictions, and the availability of reclaimed water. Of these constraints, the health concerns are by far the most important, as they pervade all potential recharge projects. Health authorities emphasize that indirect potable reuse of reclaimed wastewater through groundwater recharge encompasses a much broader range of potential risks to the public's health than nonpotable uses of reclaimed water. Because the reclaimed water eventually becomes drinking water and is consumed, health effects associated with prolonged exposure to low levels of contaminants and acute health effects from pathogens or toxic substances must be considered. Particular attention must be given to organic and inorganic substances that may elicit adverse health responses in humans after many years of exposure.

HISTORICAL DEVELOPMENT

In the early 1970s several water-quality control plans (Basin Plans) were developed under the direction of the State Water Resources Control Board (SWRCB). The Basin Plans identified as many as 36 potential projects for groundwater recharge in the state. Regulatory agencies involved in wastewater reclamation and reuse play a key role in the management of California's water resources and any projects involving the recharge of groundwater with reclaimed water (see Box). In 1973, the Department of Health Services (DOHS) prepared a position statement in response to proposals in the Basin Plans for augmentation of domestic water sources with reclaimed water. Three uses of reclaimed water were considered in the statement: groundwater recharge by surface spreading, direct injection into an aquifer suitable for use as a domestic water source, and direct discharge of reclaimed water into a domestic water supply.

Position statement. The DOHS position statement recommended against direct discharge into a domestic water-supply system and direct injection into aquifers used as a source of a domestic water supply stating that some organic constituents of wastewater are not well enough understood to permit setting limits and creating treatment-control systems. In particular, the ingestion of water reclaimed from wastewater may produce long-term health effects associated with the stable organic materials that remain after treatment. It also stated that injection to prevent saline water intrusion could be considered in the future. With regard to surface spreading, the position statement contained the following: surface spreading appears to have great potential; information relative to health effects is uncertain; if new information indicates adverse effects are created with recharge, closure of basins may be necessary; specification of allowable percentages of reclaimed water in groundwater is inappropriate at this time because of a lack of information on health effects; proposals for the recharge of small basins with large quantities of reclaimed water will not be

Groundwater recharge, occurring at the Rio Hondo Spreading Grounds in Los Angeles, represents a large potential use of reclaimed water in California.

Sanitation Districts of Los Angeles County

Milestones in Historical Development of Groundwater Recharge

1962 The first large-scale planned operation for groundwater recharge was implemented when secondary effluent from the Whittier Narrows Water Reclamation Plant in Los Angeles County was spread in the Montebello Forebay area of the Central Groundwater Basin.

1973 The California Department of Health Services (DOHS) developed a position statement on the uses of reclaimed water involving ingestion, essentially placing a moratorium on new projects for groundwater recharge.

1975 The State of California convened a Consulting Panel on the Health Aspects of Wastewater Reclamation for Groundwater Recharge to provide recommendations for research that would assist DOHS in the establishment of statewide criteria for groundwater recharge.

1976 DOHS developed draft regulations for groundwater recharge that were subsequently used as guidelines.

1976 Groundwater recharge by direct injection was initiated by the Orange County Water District to prevent saltwater intrusion.

1978 The Sanitation Districts of Los Angeles County (LACSD) initiated a 5-year Health Effects Study to investigate the health significance of using reclaimed water for groundwater replenishment.

1986 The state of California appointed a Scientific Advisory Panel on Groundwater Recharge with Reclaimed Wastewater to provide information needed for the establishment of statewide criteria for groundwater recharge.

1987 State regulatory agencies approved a 50% increase in the amount of reclaimed water that could be spread in the Montebello Forebay area.

Research Tasks

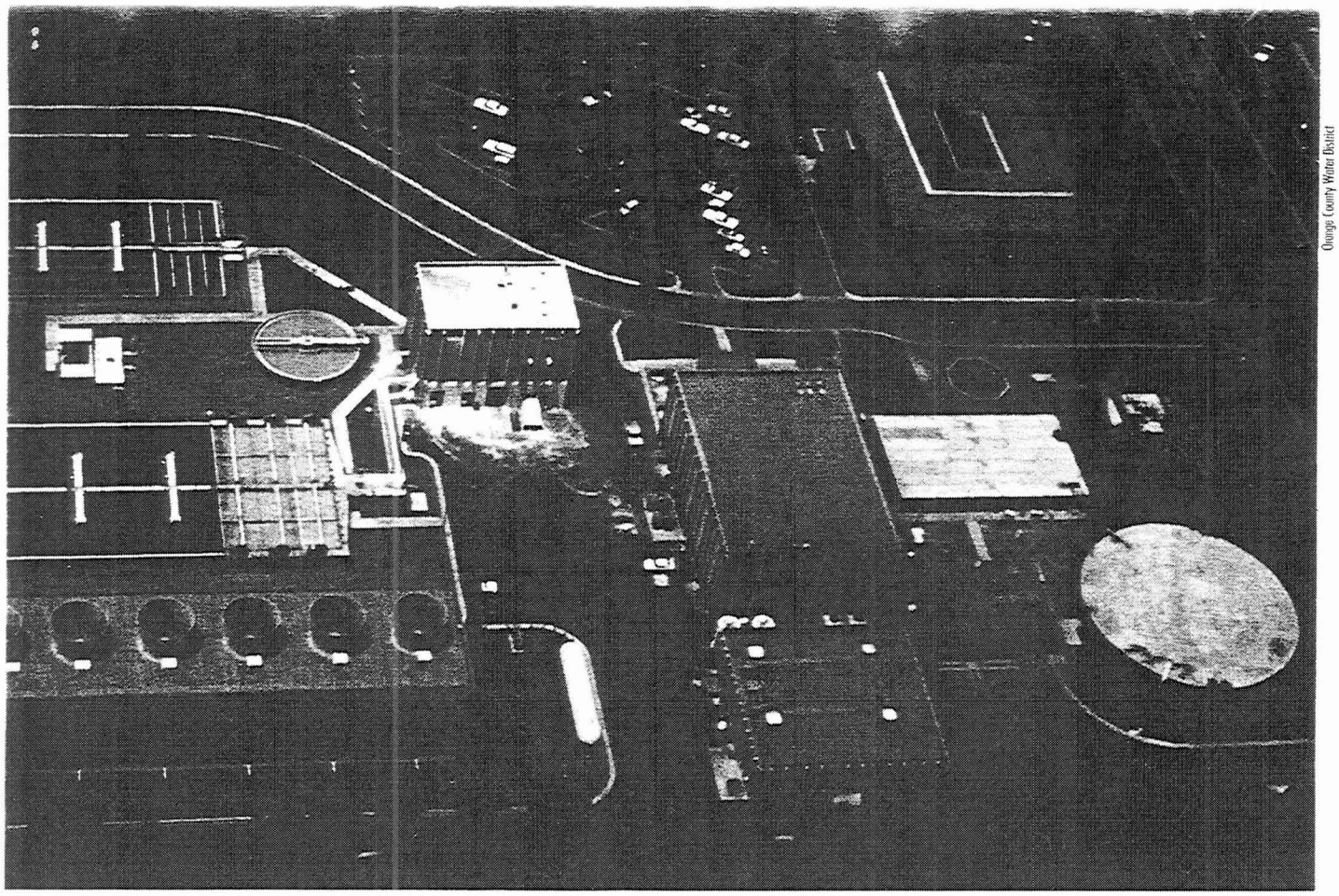
- Water-quality characterizations of groundwater, reclaimed water, and other recharge sources in terms of their microbiological and inorganic chemical content.
- Toxicological and chemical studies of groundwater, reclaimed water, and other recharge sources to isolate and identify health-significant organic constituents.
- Percolation studies to evaluate the efficacy of soil in attenuating inorganic and organic chemicals in reclaimed water.
- Hydrogeological studies to determine the movement of reclaimed water through groundwater and the relative contribution of reclaimed water to municipal water supplies.
- Epidemiological studies of populations ingesting groundwater containing reclaimed water to determine if their health characteristics differ significantly from a demographically similar control population.

recommended; proposals for recharge of large basins with small amounts of reclaimed water may be possible depending on community well locations and other conditions; and surface spreading as a future option may be a possibility.

Consulting panel. In 1975, a Consulting Panel on the Health Aspects of Wastewater Reclamation for Groundwater Recharge was established by three state agencies—DOHS, SWRCB, and the Department of Water Resources (DWR). Its purpose was to recommend a program of research that would provide information to assist DOHS in establishing reclamation criteria for groundwater recharge and to assist DWR and SWRCB in planning and implementing programs to encourage use of reclaimed water consistent with those criteria. A state-of-the-art report on the health aspects of wastewater reclamation for groundwater recharge was prepared as a background document.

The Consulting Panel confined its discussions to groundwater recharge by surface spreading and reached several conclusions. The panel concurred with DOHS that there were uncertainties regarding potential health effects associated with groundwater recharge using reclaimed wastewater. The panel suggested that comprehensive studies directed at the health aspects associated with groundwater recharge be initiated at existing projects, and that new demonstration projects would be needed to gain field information under selected and controlled conditions. The panel stated that to provide a database for estimating health risk, contaminant characterization, toxicology, and epidemiological studies of exposed populations were needed.

Health Effects Study. In the aftermath of the 1976-77 California drought, there was considerable pressure to use supplies of reclaimed water in southern California, particularly for groundwater recharge. However, an unofficial moratorium suspended new projects and the expansion of existing operations until some health-related issues associated with groundwater recharge were answered and the Consult-



Orange County Water District

Water Factory 21 is an advanced wastewater treatment facility whose effluent is used to prevent saltwater intrusion into potable water-supply aquifers.

ing Panel's recommendations were implemented. In 1978, the Sanitation Districts of Los Angeles County (LACSD) initiated a 5-year, $1.4 million study of the Montebello Forebay Groundwater Recharge Project that had been replenishing groundwater with reclaimed water since 1962. By 1978, the amount of reclaimed water spread averaged 33 x 10^6 m^3/a (26,500 ac-ft/yr) or 16% of the total inflow to the groundwater basin with no more than 40 x 10^6 m^3 (32,700 ac-ft) of reclaimed water spread in any year. The percentage of reclaimed water contained in the potable water supply ranged from 0 to 23% on an annual basis, and 0 to 11% on a long-term (1962-1977) basis.

Historical impacts on groundwater quality and human health and the relative impacts of the different replenishment sources—reclaimed water, stormwater runoff, and imported surface water—on groundwater quality were assessed after conducting a wide range of research tasks (see Box).

The study's results indicated that the risks associated with the three sources of recharged water were not significantly different and that the historical proportion of reclaimed water used for replenishment had no measurable impact on either groundwater quality or human health.[2] The Health Effects Study did not demonstrate any measurable adverse effects on the area's groundwater or the health of the population ingesting the water. The cancer-related epidemiological study findings were weakened by the minimal observed latency period (about 15 years) between first exposure and disease for human cancers. Because of the relatively short time that groundwater containing reclaimed water had been consumed, it is unlikely that examination of cancer incidence and mortality rates would have detected an effect of exposure to reclaimed water resulting from this groundwater recharge operation.

Groundwater recharge regulations. In 1976, DOHS developed draft regulations for groundwater recharge of reclaimed water by surface spreading. The proposed criteria were principally directed at the control of stable organics. The level of treatment specified in the draft regulations was conventional secondary treatment followed by carbon adsorption and percolation through at least 3 m (10 ft) of unsaturated soil. Reclaimed water-quality requirements were specified for inorganic chemicals, pesticides, radioactivity, chemical oxygen demand (COD), and total organic carbon (TOC). Requirements for groundwater quality were specified for inorganic chemicals and pesticides. An effluent monitoring program was proposed for 20 specific organic compounds. The draft regulations

Table 1—Analyses of Reclaimed Water—Montebello Forebay, 1988-1989

Constituent	Units	San Jose Creek	Whittier Narrows	Pomona	Discharge limits
Arsenic	mg/L	0.005	0.004	<0.004	0.05
Aluminum	mg/L	<0.06	<0.10	<0.08	1.0
Barium	mg/L	0.06	0.04	0.04	1.0
Cadmium	mg/L	ND	ND	ND	0.01
Chromium	mg/L	<0.02	<0.03	<0.03	0.05
Lead	mg/L	ND	ND	<0.05	0.05
Manganese	mg/L	<0.02	<0.01	<0.01	0.05
Mercury	mg/L	<0.0003	ND	<0.0001	0.002
Selenium	mg/L	<0.001	0.007	<0.004	0.01
Silver	mg/L	<0.005	ND	<0.005	0.05
Lindane	µg/L	0.05	0.07	<0.03	4
Endrin	µg/L	ND	ND	ND	0.2
Toxaphene	µg/L	ND	ND	ND	5
Methoxychlor	µg/L	ND	ND	ND	100
2,4-D	µg/L	ND	ND	ND	100
2,4,5-TP	µg/L	<0.11	ND	ND	10
Suspended solids	mg/L	<3	<2	<1	15
BOD	mg/L	7	4	4	20
Turbidity	TU	1.6	1.6	1.0	2
Total coliform	No./100mL	<1	<1	<1	2.2
Total dissolved solids	mg/L	598	523	552	700
Nitrate and nitrite	mg/L	1.55	2.19	0.69	10
Chloride	mg/L	123	83	121	250
Sulfate	mg/L	108	105	82	250
Fluoride	mg/L	0.57	0.74	0.50	1.6

ND means not detected.

restricted the maximum application of reclaimed water to not more than 50% of the total water spread during a 12-month period. A minimum residence time of 1 year in the underground before groundwater withdrawal was specified. Other proposed requirements included detailed reports on hydrogeology and spreading operations, establishment of a program to control industrial sources, development of contingency plans, and implementation of a program to monitor the health of the population receiving reclaimed water. Because the proposed regulations were based on the worst-case situation and it would have been virtually impossible for any individual project to comply with all of the requirements, the proposed regulations were not adopted as statewide criteria but were used as guidelines for new projects on groundwater recharge.

The DOHS revised the Wastewater Reclamation Criteria in 1978 to require that reclaimed water used for groundwater recharge of aquifers carrying domestic water supplies by surface spreading be of a quality that fully protects public health and that recharge recommendations be based on all relevant aspects of each project. Factors to be considered included treatment provided, effluent quality and quantity, spreading-area operations, soil characteristics, hydrogeology, residence time, and distance to withdrawal. The amendments required that the State Department of Heath Services (DOHS) hold public hearings before projects were approved.

Scientific Advisory Panel. In 1986, California commissioned a Scientific Advisory Panel on Groundwater Recharge with Reclaimed Wastewater that offered several recommendations for statewide water-reuse activities. The Scientific Advisory Panel concurred with the Health Effects Study's findings. The panel advised that the best available water in an area should be reserved for drinking water, the Whittier Narrows Groundwater Replenishment Project should continue, recharge via spreading is preferable to injection, reclaimed water should be disinfected before injection or spreading, and disinfection should not produce harmful by-products. The panel stated that available treatment processes can adequately remove organic constituents of concern, all proposed groundwater recharge projects should include prospective health surveillance of populations, biochemical tests of concentrates are necessary to determine whether likely harmful substances are present at low levels, state-of-the-art toxicology studies with animals are needed for risk evaluation, and there should be continued analytical chemistry investigation and monitoring to identify and quantify chemical constituents.

MAJOR GROUNDWATER-RECHARGE PROJECTS

Two significant projects for groundwater recharge have been implemented in California: one in Montebello Forebay and another in Orange County. Replenishing groundwater basins is accomplished by artificial recharge of aquifers in the Montebello Forebay area of south-central Los Angeles County. Waters used for recharge by surface spreading include local stormwater runoff, imported surface water from the Colorado River and state project, and reclaimed municipal wastewater. The latter has been used as a source of replenishment since 1962, when approximately 15 x 10^6 m^3/a (12,000 ac-ft/yr) of disinfected activated sludge from the LACSD Whittier Narrows Water Reclamation Plant's (WRP) secondary effluent was spread in the Montebello Forebay that has an estimated usable storage capacity of 960 x 106 m^3 (780,000 ac-ft). In 1973, the San Jose Creek WRP was placed in service and supplied secondary effluent for recharge. In addition, effluent from the Pomona WRP that is not reused for other purposes is discharged into San Jose Creek, a tributary of the San Gabriel River, and ultimately becomes a source for recharge in the Montebello Forebay. The use of effluent from the Pomona WRP is expected to decrease as the reclaimed water is used more for irrigation and industrial applications in the Pomona area.

In 1978, all three reclamation plants were upgraded to provide tertiary treatment with dual-media filtration or filtration with activated carbon and chlorination/dechlorination.[3] The groundwater replenishment program is operated by the Los Angeles County Department of Public Works (DPW), while overall management of the groundwater basin is administered by the Central and West Basin Water Replenishment District. The DPW has constructed special spreading areas designed to increase the indigenous percolation capacity. Specifically, this activity has consisted of modifications to the San Gabriel River channel and construction of off-stream spreading basins adjacent to the Rio Hondo and San Gabriel rivers. The Rio Hondo

spreading basins have 173 ha (427 ac) available for spreading and the San Gabriel River spreading grounds have 91 ha (224 ac).

Under normal operating conditions, batteries of basins are rotated through a 21-day cycle. The cycle consists of three 7-day periods during which the basins are filled to maintain a constant depth, the flow to the basins is terminated, and the basins are allowed to drain and dry out thoroughly. This wetting and drying operation serves several purposes, including maintenance of aerobic conditions in the upperstrata of the soil and vector control in the basins.

The reclaimed water produced by each treatment facility complies with primary drinking-water standards and meets total coliform and turbidity requirements of less than 2.2 MPN/100 mL and 2 NTU, respectively. Analysis of samples taken at three WRPs from October 1988 through September 1989 provides examples of reclaimed water quality (Tables 1 and 2). The WRPs tested for some constituents in samples taken daily and others in samples taken bimonthly to provide these yearly averages.

In 1987, conceptual authorization was given to increase the amount of reclaimed water used to replenish the Montebello Forebay by approximately 50% over 3 years to allow incremental evaluation, contingent on data generated by an expanded monitoring program. The other general requirements limited the total quantity of reclaimed water spread in any year to 50% of the total inflow to the basin. These requirements, based on an annual running average, stipulated that the reclaimed water must meet all California drinking-water standards and action levels— concentrations of contaminants in drinking water at which adverse health effects would not be anticipated to occur. Approval was also contingent upon demonstrating that there was no measurable increase in organic contaminants in the groundwater caused by the surface spreading of reclaimed water. Since the initial authorization, three incremental increases totaling 21.3×10^6 m^3/a (17,300 ac-ft/yr) have been approved, increasing the quantity of reclaimed water used for groundwater recharge to 62 x 106 m^3/a (50,000 ac-ft/

Table 2—Organic Analyses of Reclaimed Water—Montebello Forebay, 1988-1989

Constituent	Average Concentrations, µg/L			
	San Jose Creek	Whittier Narrows	Ponoma	Discharge limits, µg/L
Atrazine	ND[a]	ND	ND	3
Simazine	ND	ND	ND	10
Methylene chloride	<2.1	8.6	<4.7	40
Chloroform[c]	5.0	4.6	5.5	[d]
1,1,1-Trichloroethane	<1.0	<1.6	<0.5	200
Carbon tetrachloride	<0.2	<0.3	ND	0.5
1,1-Dichloroethane	<0.2	ND	ND	6
Trichloroethylene	<0.2	ND	<0.3	5
Tetrachloroethylene	<0.8	<0.5	4.1	5
Bromodichloromethane[b]	0.7	<0.6	<0.9	10
Dibromochloromethane[b]	<0 4	<0.3	<0.5	10
Bromoform[b]	<0.3	ND	ND	10
Chlorobenzene	ND	ND	<0.3	30
Vinyl chloride	ND	ND	ND	0.5
o-Dichlorobenzene	<0.7	<0.5	ND	130
m-Dichlorobenzene	ND	ND	ND	130
p-Dichlorobenzene	<1.8	<1.8	ND	5
1,1-Dichloroethane	ND	<0.2	ND	5
1,1,2-Trichloroethane	ND	ND	ND	32
1,2-Dichloroethane	<0.2	<0.3	ND	0.5
Benzene	<0.2	<0.2	ND	1
Toluene	ND	<0.5	ND	100
Ethyl benzene	<0.2	<0.4	<0.3	680
o-Xylene	<0.4	<0.4	<0.4	1750
p-Xylene	<0.4	<0.7	<0.3	1750
Trans-1,2-dichloroethylene	ND	ND	ND	10
1,2-Dichloropropane	ND	ND	ND	5
2 Cis-1,3-Dichloropropene[c]	ND	ND	ND	0.5
Trans-1,3-dichloropropene[c]	ND	ND	ND	0.5
1,1,2,2-Tetrachloroethane	ND	ND	ND	1
Freon 11	ND	ND	ND	150
Pentachlorophenol	ND	ND	ND	30

[a] ND means not detected.
[b] Limit for total trihalomethanes is 100 µg/L.
[c] Limit for total of both isomers is 0.5 µg/L.

Regulatory Authority

The principal agencies involved in wastewater reclamation and reuse in California are the California Department of Health Services (DOHS), local health agencies, the State Water Resources Control Board (SWRCB), and the nine California Regional Water Quality Control Boards (RWQCBs).

The SWRCB and RWQCBs have the primary responsibility for controlling and protecting the water quality in California, and the SWRCB is also responsible for administering water rights. The DOHS has the authority and responsibility to establish health-related standards for wastewater reclamation, including groundwater recharge, and reviews project proposals and individual requirements for wastewater reclamation. If it is determined that contamination exists because of using reclaimed water, DOHS and local health agencies have the authority to order abatement of contamination and issue peremptory orders. Local health agencies can impose requirements more stringent than those specified by DOHS.

The Porter-Cologne Water Quality Control Act gives authority to the nine RWQCBs to establish water-quality standards, to prescribe and enforce requirements for waste discharge to protect surface water and groundwater quality, and, in consultation with DOHS, to prescribe and enforce reclamation requirements. Thus, DOHS's criteria for wastewater reclamation are enforced by the regional boards, and each project must have a permit from the appropriate RWQCB conforming to the DOHS criteria.

Table 3—Water Factory 21 Injection-Water Quality

Constituent	Discharge limits	Injection water
	Concentration in mg/L	
Sodium	115	82
Sulfate	125	56
Chloride	120	84
Total dissolved solids	500	306
Hardness	180	60
pH	6.5-8.5	7.0
Ammonia nitrogen	—	4.7
Nitrate nitrogen	—	0.4
Total nitrogen	10	5.8
Boron	0.5	0.4
Cyanide	0.2	<0.01
Fluoride	1.0	0.5
MBAS	0.5	0.5
	Concentration in μg/L	
Arsenic	50	<5.0
Barium	1000	18
Cadmium	10	0.6
Chromium	50	<1.0
Cobalt	200	<1.0
Copper	1000	4.7
Iron	300	33
Lead	50	<1.0
Manganese	50	4.3
Mercury	2	<0.5
Selenium	10	<5.0
Silver	50	3.3

yr), or approximately 30% of the total inflow to the Montebello Forebay. This level of reuse represents a significant effort in water conservation corresponding to the replacement of potable water that would otherwise be used by about 50,000 households.

Additional research since the completion of the Health Effects Study conducted by LACSD included an evaluation of the efficiency of LACSD's full-scale carbon filters for removing mutagenicity as determined by the *Salmonella* microsome assay.[4] Results from this work indicate that average mutagenicity removals of 80% could be achieved based on a 10-minute, empty-bed contact time, and that the effects of chlorine disinfection on mutagenic activity vary significantly. These later results suggest that chlorine can oxidize and thus deactivate some types of mutagens, but also can react with available organic matter to create more mutagens in a given sample.

Ongoing research has focused on the development of a groundwater tracer suitable for characterizing the movement of reclaimed water in groundwater basins. The study has thus far evaluated a series of alkyl pyridone sulfonate (APS) compounds and several fluorocarbon compounds in the laboratory to measure the degree of adsorption of these compounds on soils and their ability to withstand photodecomposition and biodegradation under aerobic and anaerobic conditions. Volatility studies and biological assays have been conducted to determine the potential of the tracer compounds to elicit acute toxicity or mutagenicity. The laboratory phase of study has been completed and the second phase of study will consist of investigations to verify the laboratory results under actual field conditions.

Additional research has been proposed to provide comparative, supplemental data for the Health Effects Study's findings. Plans call for similar toxicological and chemical procedures to be used to characterize any changes in reclaimed water or groundwater quality that might have occurred since the study's samples were originally collected for evaluation. Additionally, the proposed work would attempt to use current techniques to learn more about the characteristics of compounds in mutagenic fractions, thereby providing a better understanding of the origins and health significance of these compounds and the alternatives available for their removal.

Water Factory 21 direct injection project. A project involving groundwater recharge by the injection of reclaimed water is operated by the Orange County Water District (OCWD). The OCWD first began pilot studies in 1965 to determine the feasibility of using effluent from an advanced wastewater treatment (AWT) facility in a hydraulic barrier to prevent the encroachment of saltwater into aquifers carrying potable water supplies. Construction of an AWT facility known as Water Factory 21 was started in 1972 in Fountain Valley, and injection operations began in 1976.

Water Factory 21 has a design capacity of 0.7 m^3/s (15 mgd) and can treat the secondary effluent's activated sludge from the adjacent Orange County Sanitation District's (OCSD) Sewage Treatment Plant by the following unit operations: lime clarification for removal of suspended solids, heavy metals, and dissolved minerals; air stripping (not currently in service) for removal of ammonia and volatile organic compounds; carbonation for pH control, mixed-media filtration for removal of suspended solids, adsorption with activated carbon for removal of dissolved organics; reverse osmosis (RO) for demineralization; and chlorination for biological control and disinfection. Because of a required 500-mg/L limitation of total dissolved solids before injection, RO is used to demineralize up to 0.2 m^3/s (5 mgd) of the wastewater used for injection.

The feed water to the RO plant is effluent from the mixed-media filters. Effluent from carbon columns is disinfected and blended with RO-treated water. Activated carbon is regenerated on site. Solids from the settling basins are incinerated in a multiple-hearth furnace from which lime is recovered and reused in the chemical clarifier. Brine from the RO plant is pumped to OCSD's facilities for ocean disposal.

Reclaimed water produced at Water Factory 21 is injected into a series of 23 multi-casing wells providing 81 individual injection points into four aquifers to form a seawater-intrusion barrier known as the Talbert Injection Barrier. The injection wells are located approximately 5.6 km (3.5 miles) inland from the Pacific Ocean. There are seven extraction wells not currently being used located between the injection wells and coast. Before injection, the product water is blended 2:1 with deep-well water from an aquifer not subject to contamination. Depending on basin conditions, the injected water flows toward the ocean forming a seawater barrier, flows inland to augment the potable groundwater supply, or both.

The AWT processes at Water Factory 21 reliably produce high-quality water. No coliform organisms were detected in any of the 179 samples of Water

Factory 21 effluent tested during 1988. Although the discharge permit requires OCWD to institute a virus monitoring program that is acceptable to DOHS, virus sampling is not being conducted at present. A virus monitoring program conducted from 1975 to 1982 demonstrated to the satisfaction of the state and county health agencies that Water Factory 21 produces effluent that is essentially free of measurable levels of viruses. The average turbidity of filter effluent was 0.22 FTU and did not exceed 1.0 FTU during 1988. The average COD and TOC concentrations for the year were 8 mg/L and 2.6 mg/L, respectively. The effectiveness of Water Factory 21's treatment processes for the removal of inorganic and organic constituents is shown in the present water-quality data for the blended injection water (Tables 3 and 4). Fifty-three specific volatile organic compounds were not detected in injection water samples, which were blended in a 2:1 ratio with deep-well water before analysis.

The OCWD has developed a plan for groundwater management in response to potential water shortages and local water-quality problems. The plan documents several potential projects to reuse wastewater by groundwater recharge. Included is the possible expansion of Water Factory 21 to provide injection water for seawater-intrusion barriers at Sunset and Bolsa Gaps in Orange County, and for injecting reclaimed water directly into the groundwater basin in central Orange County. Another project under consideration is the construction of an AWT facility, similar to Water Factory 21, that would provide reclaimed water for a seawater-intrusion barrier at Alamitos Gap. Based on current growth projections, wastewater treatment capacity in the service area of OCSD will be exceeded by the year 2000. A possible project involves construction of a wastewater reclamation plant in the Anaheim area, where as much as 1.1 m^3/s (25 mgd) of reclaimed water could be used for various types of reuse, including groundwater recharge by direct injection.

Table 4—Volatile Organic Compounds in Injection Water—Water Factory 21

Constituent	Injection water µg/L
Methylene chloride	1.0
Chloroform	5.4
Dibromochloromethane	1.1
Chlorobenzene	Trace amount
Bromodichloromethane	3.7
Bromoform	0.8
1,1,1-Trichloroethane	Trace amount

The Goals and Objectives of the Guidelines for Groundwater Recharge with Reclaimed Municipal Wastewater

- To plan and encourage efficient use of the state's water resources and increase the reliability of the water supply by implementing the safe use of treated municipal wastewater for groundwater recharge
- To guide the RWQCBs in establishing objectives for groundwater quality and requirements for wastewater reclamation that will adequately protect health and environment while encouraging optimum use of the region's water resources
- To ensure that groundwater recharge with reclaimed wastewater, whether planned or incidental, is regulated in a consistent manner
- To assist planning for groundwater recharge with reclaimed wastewater by providing the criteria and guidelines that detail the required information for review by regulatory agencies

GUIDELINES FOR GROUNDWATER RECHARGE

Groundwater recharge with reclaimed water represents a large potential use of reclaimed water in California; yet there are few planned recharge projects in the state, partly because of economic considerations and continuing health concerns. This situation, coupled with the knowledge that unplanned or incidental recharge with wastewater is widespread and relatively uncontrolled, suggested that it was essential to undertake a comprehensive review of existing regulations and establish statewide policies and guidelines for planning and implementing new projects for groundwater recharge. In a coordinated effort to address these needs, DOHS, SWRCB, and DWR are developing a document titled "Guidelines for Groundwater Recharge with Reclaimed Municipal Wastewater." It is anticipated that the guidelines will be adopted by the DOHS in 1991 (see Box).

The proposed guidelines include principles, permitting procedures, and criteria for groundwater recharge. The criteria for surface spreading and injection of reclaimed water will address treatment processes, treatment reliability, water quality, monitoring, dilution, time underground, distance to withdrawal, and operational procedures. It is anticipated that criteria for groundwater recharge will be somewhat flexible and take into consideration site-specific conditions such as percolation rate and depth to groundwater. The criteria are currently under development by DOHS, with input from other state and local regulatory agencies, and operating agencies. The guidelines will also include a background document to provide a detailed rationale for the criteria. ■

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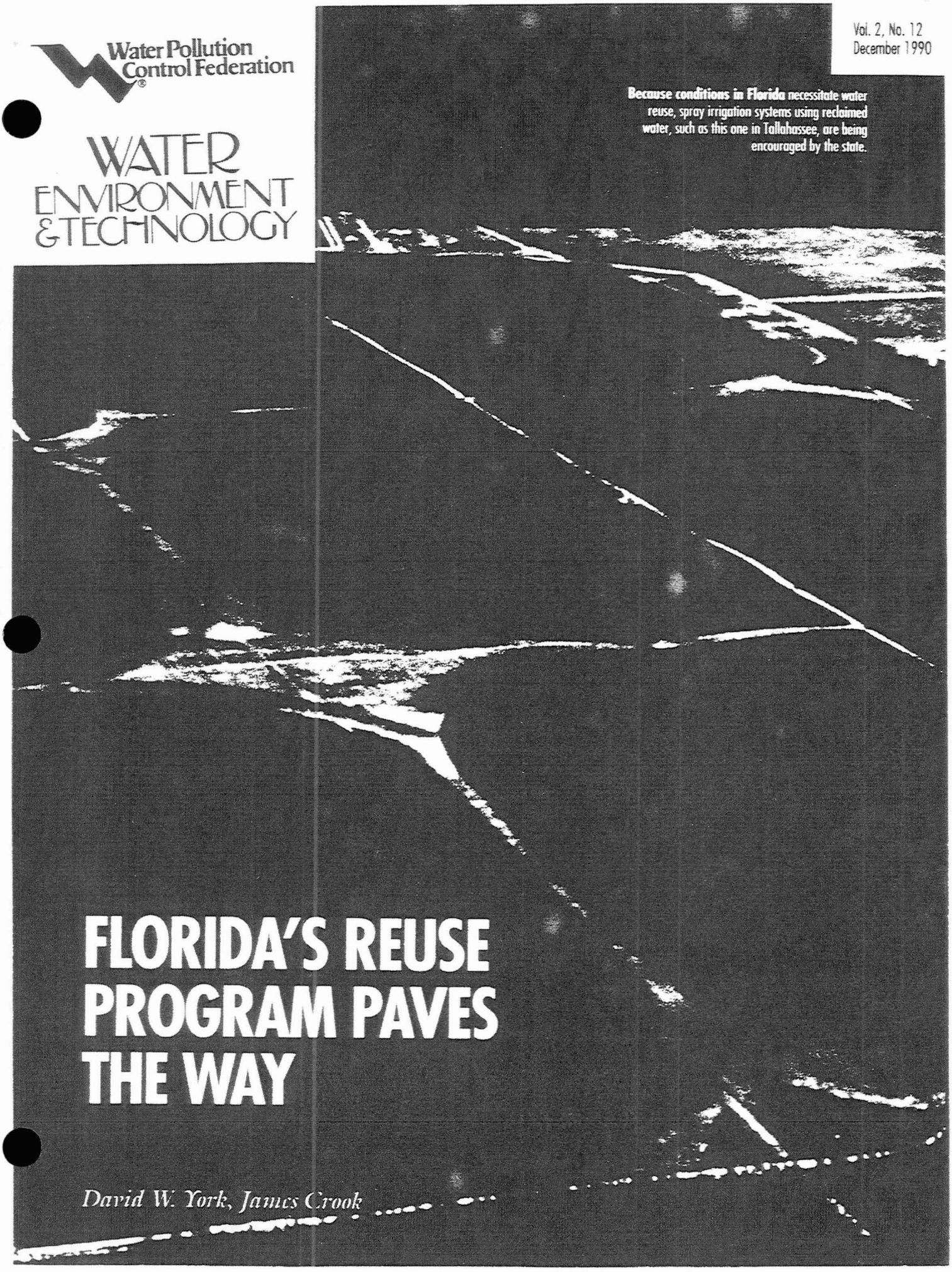


Because conditions in Florida necessitate water reuse, spray irrigation systems using reclaimed water, such as this one in Tallahassee, are being encouraged by the state.

FLORIDA'S REUSE PROGRAM PAVES THE WAY

David W. York, James Crook

Florida is different than the major reuse states in the semi-arid southwest U.S. In Florida, it rains an average of 54 in./yr and the state seemingly has abundant water resources—particularly groundwater, which accounts for about 90% of all water used for domestic purposes. However, there are increasing demands on the state's water resources.

Florida continues to face rapid population growth. Its population, which nearly doubled from 1960 to 1980, continues to increase by more than 6000 persons each week. Between 1980 and 1990 the population rose 33%, and from 1990 to 2000 the population is expected to grow an additional 19%.

Almost 79% of Florida's 13 million people lives near the coast, and about 82% of the anticipated population growth will occur in coastal counties. These coastal growth areas are served primarily by shallow aquifers that are most vulnerable to overdraft and saltwater intrusion.

These conditions necessitate water reclamation and reuse. The state has developed programs that encourage the reuse of reclaimed water and comprehensive regulations that govern reuse projects. The rules provide detailed requirements for development of reuse projects that involve irrigation in public access areas such as parks, playgrounds, and golf courses, as well as irrigation of residential property and edible crops and must address the use of reclaimed water for fire protection, toilet flushing, and aesthetic purposes such as decorative ponds and fountains. The reuse rules provide requirements for preapplication treatment, reliability, operation control, buffer zones, storage, cross-connection control, and other design and operational features. These rules also provide a mechanism for limited discharge of excess reclaimed water during wet-weather, high-stream-flow conditions when demand for reclaimed water is lowered. Such limited wet-weather discharge provisions should encourage development of reuse projects by reducing storage requirements.

Florida Department of Environmental Regulation

DEVELOPMENT OF REUSE

During the last 20 years, the primary driving force behind implementation of reuse projects in Florida has been effluent disposal. While the state has many streams, they typically have low flows, are shallow, have low gradients, flow slowly, are warm all year, and flow into lakes or estuaries. Most surface waters in Florida simply will not assimilate large quantities of effluent. As a result, many communities have turned to land application to dispose of unwanted effluent.

Regulations developed in the early 1980s for reuse and land application are in the manual, *Land Application of Domestic Wastewater Effluent in Florida*[1], that contains detailed design and operation requirements for slow-rate land application systems, rapid-rate land application systems, absorption fields, overland flow systems, and other land application systems. Irrigation of public access areas or edible crops was allowed, but requirements for such activities were incomplete.

The land application manual was designed to be used in conjunction with *Chapter 17-6, Florida Administrative Code (FAC)*, titled "Wastewater Facilities." As shown in Table 1, four levels of disinfection were defined in the rule.

The high-level disinfection requirements were developed in the early 1980s based largely on the testimony of epidemiologists and virologists before the Florida Environmental Regulation Commission. The criteria were designed to provide treated water that was essentially pathogen free. Where chlorine was used for disinfection, maintenance of a 1.0-mg/L total chlorine residual after a 15-minute contact time at maximum daily flow or after a 30-minute contact time at average daily flow was to be accepted as evidence that the fecal coliform criteria would be met.

Secondary treatment was established in *Chapter 17-6, FAC*, as the minimum pretreatment level for most land application and reuse systems. Florida's definition of secondary treatment requires that the wastewater treatment facility be designed to produce an effluent containing not more than 20 mg/L of biochemical oxygen demand (BOD) and total suspended solids (TSS) or 90% removal of BOD and TSS, whichever is more stringent. The annual average BOD and TSS concentrations may not exceed 20 mg/L and the monthly average may not exceed 30 mg/L. A lower level of secondary treatment—40 to 60 mg/L for BOD and TSS—was allowed for overland flow systems and for some underdrained irrigation systems.

In September 1989, *Chapter 17-6, FAC*, was rewritten into a new series of rules. Regulations governing domestic wastewater treatment and disinfection are now found in *Chapter 17-600, FAC*, titled "Domestic Wastewater Facilities."

During the 1970s and 1980s, the number of projects involving reuse

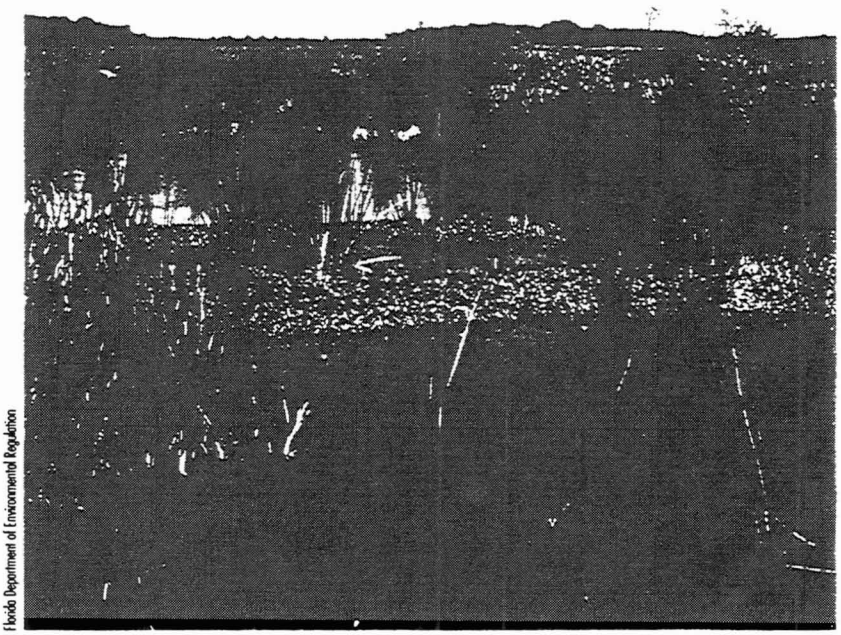
Table 1 - Disinfection Levels Defined by Florida Rules

Disinfection level	Fecal coliform limit	Application
High-level	No detectable	Public access maximum fecal coliform TSS 5 mg/L. Irrigation and irrigation of edible crops, for discharge to Class I surface waters (potable water supplies).
Intermediate		14/100 mL. For discharge to waters tributary to Class II surface waters (shellfish propagation or harvesting).
Basic	200/100 mL	For most land application systems, for most discharges to surface waters.
Low-level	2400/100 mL maximum	For overland flow systems and some underdrained irrigation systems.

or land application increased substantially. By 1985, more than 100 individual projects involved some form of reuse, including several excellent reuse projects such as the St. Petersburg dual water distribution system, the Tallahassee spray irrigation system, and the CONSERV II citrus irrigation project serving Orlando and Orange Counties.

The *1990 Reuse Inventory*[2] identified about 200 reuse projects in Florida. These projects use about 320 mgd of reclaimed water for a wide range of beneficial uses.

With the growing popularity and acceptance of water reuse projects, the state has begun to promote water reclamation. Statewide comprehensive planning has been implemented to ensure that adequate infrastructure is provided. Increased attention is being placed on protection of water resources and provision of adequate water supply. Reuse of reclaimed water is receiving greater attention as a means to reduce demands on potable water resources and recharge groundwater.



Florida Department of Environmental Regulation

Wastewater restoration, occurring in this Orlando, Fla., wetland, is identified as a reuse application for surface-water enhancement.

THE STATE'S REUSE PROGRAM

Beginning in 1987, the Florida Department of Environmental Regulation embarked on an ambitious program of rule making designed to facilitate and encourage reuse of reclaimed water. Three rules were effected: *Chapter 17-6, FAC,* "Wastewater Facilities", *Chapter 17-40, FAC,* "Water Policy", and *Chapter 17-610, FAC,* "Reuse of Reclaimed Water and Land Application."

In addition, 1989 state legislation and other related rule making also affected reuse in Florida.

Updated reuse rules were developed with significant assistance from a technical advisory committee consisting of representatives of the Florida Pollution Control Association, Florida Engineering Society, American Water Works Association Florida Section, American Water Resources Association, a representative of a private utility, and the former head of California's reuse program. Committee members offered a wealth of experience and expertise covering a wide range of reuse activities.

Consistent definitions for reuse and reclaimed water were included in all three rules. *Reclaimed water* is water that has received at least secondary treatment and is reused after flowing out of a wastewater treatment facility. *Reuse* is the deliberate application of reclaimed water in compliance with applicable rules for a beneficial purpose.

The rules identify landscape irrigation, agricultural irrigation, aesthetic uses, groundwater recharge, industrial uses, and fire protection as legitimate beneficial purposes. Environmental enhancement of surface waters resulting from discharge of reclaimed water that has received at least advanced wastewater treatment or from discharge of reclaimed water for wetlands restoration also are identified as reuse applications.

Chapter 17-40, FAC The "Water Policy" rule outlines the state's policy for the use and regulation of water. It provides general guidance to the state's five water-management districts that are responsible for water-quantity management, including the consumptive-use permitting program.

An October 1988 amendment to *Chapter 17-40, FAC,* created a program for mandatory reuse of reclaimed water. The water-management districts were required to assess the water resources within their jurisdictions—including an estimate of water needs and sources for the next 20 years—and to publish a comprehensive district water-management plan. As part of this planning activity, the water-management districts were required to identify critical water-supply problem areas. Reuse will be required within critical water-supply problem areas that exist today, and in areas that are projected to develop over a 20-year planning horizon. The program will be in full operation by November 1991.

The rule also allows the water-management districts to require reuse outside of critical water-supply problem areas if reclaimed water is readily available to the applicant for a consumptive-use permit. This measure was designed to facilitate implementation of reuse at the local level. The primary responsibility for implementation of this program rests with the water-management districts through the consumptive-use permitting process.

Chapter 17-6, FAC Amendments to the rule focused on two areas. First, the high-level disinfection requirements were modified to reflect existing technology and experience. Revised high-level disinfection criteria include requirements that 75% of all fecal coliform observations be less than the detection limit and that no sample exceed 25/100 mL for fecal coliform. Daily sampling for fecal coliform was

Table 2 - Requirements for Reuse

Parameter	Requirements
Minimum treatment level	Secondary with filtration and chemical feed, maximum TSS of 5 mg/L.
Disinfection	High-level.
Minimum system size	378.5 m^3/d (0.1 mgd) for any public access irrigation system, 1893 m^3/d (0.5 mgd) for residential lawn irrigation or edible crop irrigation.
Reliability	Class I—requires multiple units or backup units and a second power source.
Staffing	24 hr/day, 7 days/wk; may be reduced to 6 hr/day, 7 days/wk, if additional reliability measures are included.
Continuous monitoring	Required for turbidity and disinfectant residual.
Operating protocol	Required—a formal statement of how the treatment facility will be operated to ensure compliance with treatment and disinfection requirements.
Storage requirements	System storage (minimum 3 days, may be unlined) or back-up system required; golf course lakes may be used for system storage.
Reject storage	Minimum 1 day, lined, to hold unacceptable quality product water for return for additional treatment.
Limits on reuse	Only product water meeting the criteria of the operating protocol shall be released to the reuse system; reclaimed water shall not be used to fill swimming pools, hot tubs, or wading pools.
Cross-connection control	Prohibit cross-connections to potable water systems; reclaimed water shall not enter a dwelling unit; minimum standards for separation of reclaimed water lines from water lines and sewers; color coding or marking required; back-flow prevention devices required on potable water sources entering property served by reclaimed water systems; dual check valves are acceptable.
Setback distances	22.9 m (75 ft) to potable water-supply wells; otherwise, none.
Other O&M requirements	Approved operating protocol; approved cross-connection control program; documentation of controls on individual users (agreements or ordinance); assess need for industrial pretreatment program.

included as a requirement for reuse systems. The TSS limitation remains at a maximum of 5 mg/L before application of the disinfectant. Turbidity is not incorporated in the rule as a permitting parameter. However, for public access irrigation and for irrigation of edible crops, continuous on-line turbidity monitoring is required as part of the operational control provision in *Chapter 17-610, FAC* Disinfection requirements are now found in *Chapter 17-600, FAC.*

Provisions for limited wet-weather discharge were added to the "Wastewater Facilities" rule. This section is designed to facilitate discharge of reclaimed water during wet-weather, high-flow periods when demand for reclaimed water normally is reduced. When the applicant demonstrates sufficient dilution during periods of high stream flow, the state will permit a discharge with minimal water quality review. Required dilution ratios are based on the quality of the reclaimed water and the anticipated frequency of discharge:

$$SDF = P(0.085\ CBOD_5 + 0.272\ TKN - 0.484)$$

Where

SDF = minimum required stream dilution factor, dimensionless;

P = percent of the days of the year that limited wet-weather discharge will occur during an average rainfall year;

$CBOD_5$ = the treatment facility's design monthly maximum limitation for carbonaceous BOD_5 in mg/L; and

TKN = the treatment facility's design monthly maximum limitation for total Kjeldahl nitrogen expressed in mg/L of nitrogen.

The dilution ratio is increased if travel time to sensitive downstream environments such as lakes, estuaries, and water supplies is less than 24 hours. Limited wet-weather discharge provisions were subsequently relocated to *Chapter 17-610, FAC.*

Chapter 17-610, FAC The "Reuse of Reclaimed Water and Land Application" rule was adopted in 1989. It supersedes and expands upon the old land application manual.[1] The focus of this rule making was to provide detailed requirements for the design and operation of reuse projects in public access areas, including irrigation of residential lawns, parks, golf courses, landscape areas, as well as for the irrigation of edible food

crops. These requirements are contained in Part III of the rule.

Table 2 presents a summary of the key provisions of this part for public-access irrigation systems, irrigation of residential lawns, and irrigation of edible crops. Reclaimed water that has received high-level disinfection, secondary treatment, and filtration, and that meets the full requirements of Part III may also be used for toilet flushing in commercial and industrial facilities that do not contain dwelling units, for fire protection, for construction dust control, for aesthetic purposes, and for other uses.

Any reuse system regulated by Part III must provide a minimum of secondary treatment, filtration, and high-level disinfection. Class I reliability and full-time operator attendance are required; some reduction in operator attendance is allowed if additional reliability measures are provided. Each facility must develop an operating protocol; a clear statement of how the facility will be operated to ensure that only acceptable reclaimed water is discharged into the reuse system. While turbidity and disinfectant residual must be continuously monitored for operational control, these are not permit limitations. The facility must be operated such that the high-level disinfection criteria (TSS and fecal coliform limits) will be met. Unacceptable product water must be diverted to a lined, reject storage system for additional treatment before being released to the reuse system.

As shown in the Table, minimum system sizes were established for treatment facilities that make reclaimed water available for irrigation in public access areas or for irrigation of edible food crops. These minimum size limits reflect reduced confidence in a small facility's ability to continuously produce high-quality reclaimed water. Both the technical advisory committee and the Florida Department of Health and Rehabilitative Services recommended minimum size limits.

Rules that existed before 1989 allowed the irrigation of edible food crops if high-level disinfection was provided and the permit applicant demonstrated that processing of the food crop would inactivate or remove pathogens. Few edible crop irrigation systems were proposed.

The original provisions of the rule allowed irrigation of edible food crops without restriction beyond Part III requirements. This position represented a consensus from the technical advisory committee, which noted that the potential for disease transmission from an edible food crop irrigation system is not significantly different from that of a residential lawn irrigation system, as long as the full requirements of Part III are met. However, in response to concerns raised by the Florida Department of Health and Rehabilitative Services, the issue was revisited in July 1989. It was amended to prohibit direct contact of reclaimed water on edible food crops that will not be peeled, skinned, cooked, or thermally processed before human consumption. Indirect application methods such as ridge and furrow, drip irrigation, or subsurface distribution systems are still allowed for these crops. No restrictions were placed on the irrigation of citrus, tobacco, or other crops that are peeled, skinned, cooked, or thermally processed before consumption.

Other Legislation and Rule making. The Department of Environmental Regulation pursued state legislation in 1989 to allow the department to require that wastewater treatment facilities located within designated critical water-supply problem areas make reclaimed water available for reuse. Unfortunately, the resulting legislation[3] stopped short of vesting such authority. The law does require that, beginning in 1992, applicants for wastewater-management permits located within critical water-supply problem areas complete reuse feasibility studies. The law clearly establishes that reuse of reclaimed water and conservation of water are formal state objectives.

In 1989, the Department of Environmental Regulation also revised *Rule 17-302, FAC,* "Surface Water Quality Standards," and *Rule 17-4, FAC,* "Permits," to include an antidegradation policy. This policy requires that any new or expanded surface-water discharges be clearly in the public interest. The applicants for surface-water discharges must demonstrate that reuse of domestic reclaimed water is not economically or technologically reasonable.

Rule clean-up. *Chapter 17-610, FAC,* was revised in 1990. Setback distance (buffer zone) requirements were updated throughout the rules. Streamlined permitting requirements and associated forms were added. The use of reclaimed water for toilet flushing and fire protection was extended to motels, hotels, apartments, and other units where the resident does not have ready access to the plumbing system for repairs or modifications.

THE FUTURE

Reuse of reclaimed water will increase significantly during the next decade. Recent droughts in southern Florida emphasized the need for conservation of valuable potable water supplies and for reuse of reclaimed water. As the water-management districts identify critical water-supply problem areas and implement mandatory reuse provisions, additional pressures will be placed on communities to move toward reuse. Requirements for applicants for wastewater-management permits to conduct reuse feasibility studies also will focus the community's attention on the need for reuse. Continued population growth, most of which will occur in coastal areas, will increase the pressure on cities, counties, and utilities to protect valuable and fragile water resources by conserving water and reusing reclaimed water for nonpotable purposes.

The Florida Department of Environmental Regulations strongly supports reuse of reclaimed water. The goal is to increase the amount of reuse in Florida by 40% above 1987 levels by 1992. Recently adopted technical reuse rules, the mandatory reuse program, 1989 state legislation, and the antidegradation policy will contribute to the promotion of reuse. ■

David W. York is reuse coordinator for the Florida Department of Environmental Regulation in Tallahassee, Fla.; James Crook is principal engineer with Camp Dresser & McKee, Inc., in Clearwater, Fla.

REFERENCES

1. *Land Application of Domestic Wastewater Effluent in Florida.* Florida Department of Environmental Regulation, Tallahassee, Fl. (1983).

2. *1990 Reuse Inventory.* Florida Department of Environmental Regulation, Tallahassee, Fla. (1990).

3. *Section 403.064, Florida Statutes.* State of Florida, Tallahassee, Fl. (1989).

PROPOSED REVISIONS to ARIZONA'S WATER REUSE REGULATIONS

Steve Pawlowski
Arizona Department of Environmental Quality

10:45 am -- 11:20 am

GEOPURIFICATION and WATER REUSE

Herman Bouwer
U.S. Water Conservation Laboratory

11:20 am -- 11:55 am

REUSE RULES

HERMAN BOUWER

A combination of rising treatment costs for sewage effluent discharged to surface water and growing water demand is writing a new commandment for many municipalities: Waste Not Wastewater. In deciding how to accomplish that goal, applicable treatment and water quality criteria and local climate and hydrogeological conditions are critical variables.

Cities that discharge sewage effluent to surface water are under increasing pressure to reduce concentrations of heavy metals, ammonium and nitrate, and substances such as toxic organic compounds (TOCs) in their wastewater in order to better protect aquatic life and the public health in cities that use downstream water for drinking. Providing this treatment is costly, and that's making it harder and harder for municipalities to justify wasting their wastewater—especially in fast-growing areas where drinking water supplies may be reaching their limits.

These factors are prompting municipalities to look into zero discharge and complete reuse of wastewater as a less expensive way to protect the quality of streams and lakes, while conserving valuable water resources. Zero discharge alone will not guarantee pristine surface water. There may still be non-point-source pollution of the water by entry of ground water that is contaminated with agricultural and industrial chemicals. Surface runoff from cities and farms may also enter streams and degrade the water quality. However, eliminating point sources of water pollution certainly will have a beneficial effect on surface water quality.

Zero discharge is readily accomplished in dry climates, where irrigation of agricultural and urban plantings requires lots of water. The main treatment is disinfection to reduce microorganism concentrations to acceptable levels. Some municipalities may be able to trade treated effluent with irrigation districts in exchange for high-quality water that can be used to augment city drinking water supplies.

In humid climates or areas without much irrigable agriculture or vegetation, other urban uses may have to be developed. Uses of nonpotable water include industrial processes and cooling; boiler feed; construction applications such as dust control, soil settling and compaction, aggregate washing, and concrete making; fire fighting; car washing; restricted recreational areas and decorative lakes; and toilet flushing.

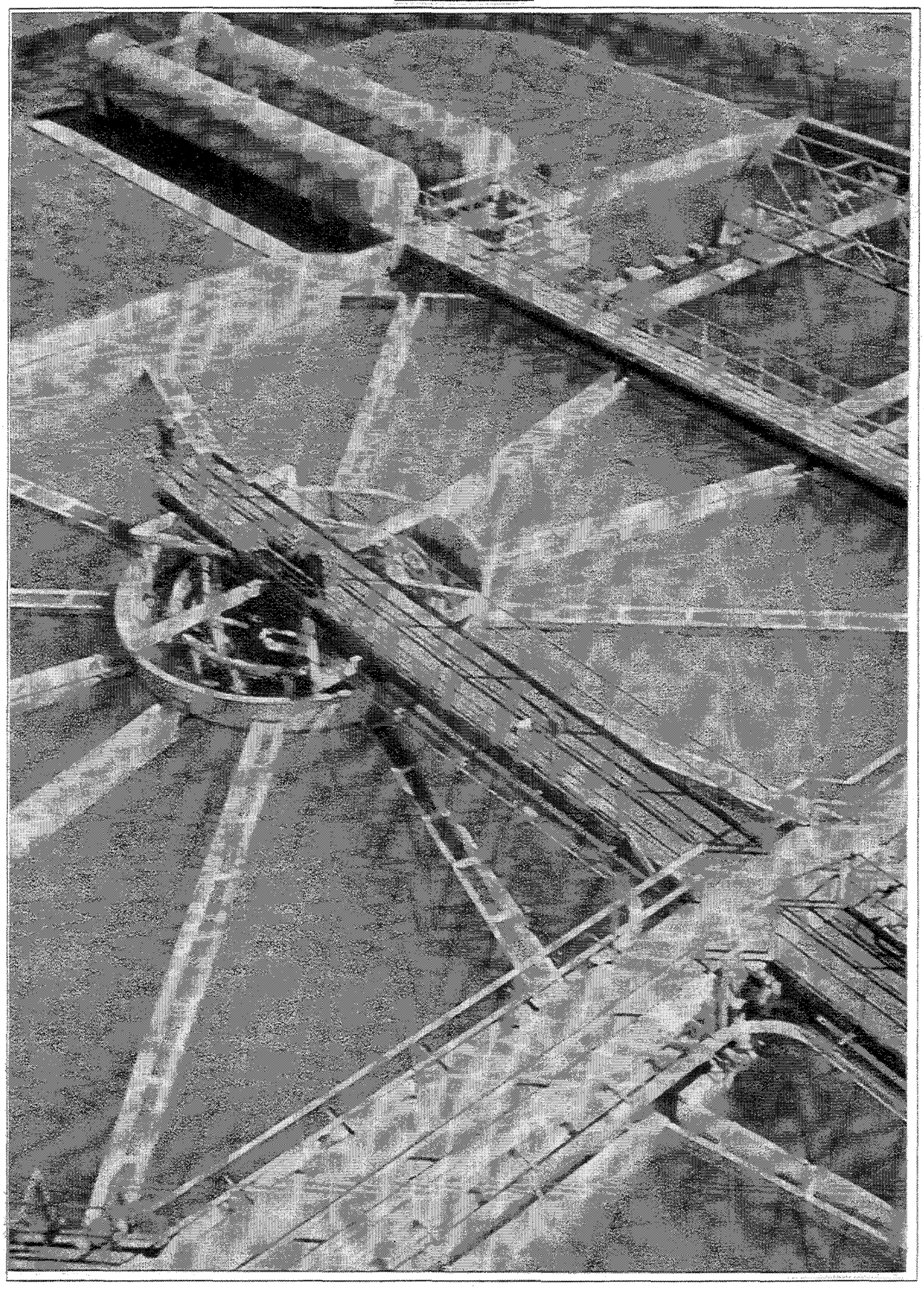
Recycling of wastewater to potability, although technically possible, is usually considered a practice of last resort. However, some municipalities are doing it, including Windhoek, South Africa and El Paso, Tex. Others, such as Denver, have implemented pilot or demonstration projects. Reuse of wastewater for drinking faces significant psychological and public acceptance obstacles, but is really not much different than using water from heavily polluted streams for municipal water supply. Cities that do this include Rotterdam at the mouth of the Meuse and Rhine, New Orleans at the mouth of the Mississippi, and Adelaide at the mouth of the Murray.

TREATMENT CRITERIA VARY

Quality and treatment criteria for agricultural use of sewage effluent become more stringent as human contact and potential for ingestion increase. The toughest standards are for unrestricted irrigation—for example, spray irrigation of lettuce and other crops that are consumed raw. There are

AT A POTABLE REUSE PLANT IN EL PASO, TEX. DESIGNED TO HELP PREVENT THE DEPLETION OF GROUND-WATER SOURCES, WASTEWATER IS TREATED TO DRINKING WATER STANDARDS PRIOR TO WELL INJECTION. STEPS INCLUDE LIME CLARIFICATION AND RECARBONATION.

Reprinted from Civil Engineering, July 1992.



now two main sets of public health water quality criteria for unrestricted irrigation with municipal wastewater.

One standard is for countries that are technically and financially capable of high technology treatment. It is patterned after California's Title 22 Effluent Reuse Standard, and requires that wastewater be essentially free from pathogenic organisms (fecal coliforms, viruses, eggs of parasitic worms) and have a low turbidity. This can be achieved with conventional primary and secondary treatment, followed by coagulation, granular media filtration, and chlorination or other disinfection. Where hydrogeological conditions are favorable for ground-water recharge with infiltration basins, the standards can also be met by filtration of the wastewater through soils and aquifers.

The second set of guidelines applies to countries that cannot or will not provide expensive and high technology treatment. Through most of the developing world, imposing the stringent California-type health standards would probably lead to no treatment at all and the use of raw wastewater for unrestricted irrigation. Established by the World Health Organization in 1989, these guidelines require a maximum fecal coliform concentration of 1,000/100 ml and a maximum concentration of helminthic eggs of 1 per liter for unrestricted irrigation. This level of quality can be achieved by lagooning with detention times of a few weeks in warm regions and longer in cooler areas. Lagooning also greatly reduces concentrations of bacteria and viruses in the effluent.

Requirements are less strict under both standards for irrigating crops that aren't consumed raw or brought raw into the kitchen. In addition to public health, agronomic factors should be considered. This means that the wastewater should meet normal quality requirements (such as salinity, sodium adsorption ratio, nitrogen, and toxic and trace elements) for irrigation water.

POTABLE-USE PROJECTS

In general, urban uses for nonpotable water require the same quality and treatment criteria as unrestricted agricultural irrigation. Potable use of sewage effluent in a recycling scheme—either in direct pipe-to-pipe systems or through aquifer injection—requires advanced wastewater treatment (AWT) after conventional primary and secondary treatment.

Normal drinking water standards cannot be used to determine whether water that has undergone AWT is suitable for drinking. Those standards apply only when the water source is relatively unpolluted. Wastewater contains a multitude of chemicals that enter the sewer system with residential and industrial discharges. It is practically impossible to develop maximum contaminant levels (MCLs) and monitor for all these chemicals after AWT. Rather than setting MCLs for all the undesirable chemicals that may be in the product water, potable recycling requires that the treatment processes be specified.

The AWT processes must be tested in pilot or demonstration projects. The suitability of the product water for drinking is then determined through chemical analyses, biomonitoring and bioassays. These projects can also be used for public information activities that help develop good community relations and cultivate acceptance of potable recycling. For full-scale recycling operations, only certain critical, mostly surrogate-type quality parameters must be monitored to make sure that the treatment processes are working. These include pH, turbidity, TOCs and fecal coliforms.

The most ambitious demonstration project involving a pipe-to-pipe reuse concept was conducted at the Denver Water Department. Completed last year, the project took conventionally treated effluent and converted it into drinking water. The project used the following treatment train, which was designed to provide the necessary redundancy and multiple barriers against contaminants: lime clarification, recarbonation, granular media filtration, ultraviolet irradiation, granular activated carbon adsorption, reverse osmosis, air stripping, ozonation, and chloramination. A final report is due this fall; in the meantime the results indicate that the reclaimed water was of equal or better quality than Denver's existing supplies.

Projecting the demonstration results to a 0.4 million m^3/day plant, costs for advanced treatment would be about $0.60 per cubic meter (1988 dollars). Primary and secondary treatment would cost another $0.10 per cubic meter. Denver has no plans for implementing large-scale potable reuse, but the costs would be comparable to those for acquiring new supplies from other sources, according to project estimates.

A potable reuse system using well injection has been operating in El Paso, Tex. since 1985 (see box). This system has a capacity of about 40,000 m^3/day and currently treats about 27,000 m^3/day. The treatment train consists of primary treatment, secondary treatment (aeration) with addition of powdered activated carbon, denitrification with addition of methanol as energy source, lime clarification, recarbonation, sand filtration, ozonation, and granular activated carbon adsorption.

Following treatment, the water is injected through wells into an aquifer, from where it is pumped for municipal use from production wells about 3 km downgradient from the injection wells. Projected underground travel times to the production wells are on the order of two to four years, but may be less due to faster flow through more permeable layers of the aquifer. The treatment process (excluding well injection) costs about $0.70 per cubic meter.

SOIL-AQUIFER TREATMENT

Well injection was chosen for the El Paso project because the ground water was relatively deep, undesirable chemicals could leach from the vadose zone, and the ground water at the top of the aquifer was of poor quality. Where conditions are more favorable, wastewater can be treated and stored for reuse with ground-water recharge systems, using shallow basins or other facilities for infiltration of primary or secondary effluent.

These systems are designed and managed as recharge-recovery systems, using various layouts of infiltration basins and wells, drains, or other collection facilities. Since water quality improvement by filtration through the soil and aquifer is often the main objective, the systems are no longer called ground-water recharge systems, but soil-aquifer treatment (SAT) or, in Europe, geopurification systems.

The performance of SAT systems is site dependent and controlled by wastewater quality, soils, hydrogeology, and climate. Pilot or experimental systems should always precede full-scale and operational systems so that the feasibility of SAT can be evaluated and the full-scale version of the system can be designed and managed for optimum performance.

Demonstration projects have included the Flushing Meadows Project and the 23rd Avenue Project in the Salt River floodplain west of Phoenix. Both projects used secondary effluent (activated sludge) from Phoenix. The vadose zone and aquifer in

PIONEERING POTABLE USE

It's often said that potable reuse of wastewater faces stiff public opposition, but the concept has been well accepted by the residents of El Paso, Tex., according to John Balliew, planning and development manager of the El Paso Water Utilities Public Service Board. In the largest potable reuse system in the U.S., the city has been using treated wastewater from the $33 million Fred Hervey Water Reclamation Plant to replenish its drinking water supplies since 1985.

Depletion of the Hueco Bolson aquifer, source of 60% of the city's water, provided a powerful incentive for El Paso's pioneering effort. The aquifer would have been drawn down to "irrecoverable levels" by 2030 if nothing was done, says Balliew. El Paso Water estimates that every 10 years the plant operates adds one year to the life of the aquifer.

To ensure that reclaimed water is of potable quality, the effluent is monitored after each step in the advanced wastewater treatment (AWT) process and again at the effluent structure for microbiological parameters, nitrates and turbidity, says Balliew. If something goes wrong along the way, the wastewater can be shifted to a pond and retreated. Once the water leaves the plant, random samples are collected through the injection system at each well through a series of monitoring wells, at the reservoir and from each noninjection user and analyzed. All Safe Drinking Water Act parameters are checked four times yearly.

The plant is also participating in the High Plains States Groundwater Demonstration Program. Sponsored by the Bureau of Reclamation, the program is designed to identify technologies and water resource planning to recharge aquifers in high plains states. With funding of $150,000 per year for five years, they are monitoring water at the plant "for other things we wouldn't have a chance to test otherwise," says Balliew, including organic compounds, rare metals, and microbial studies. They are also working to identify a "tracer compound," to measure the proportion of reclaimed water in samples. "Reused water is so close to native ground water that it's hard to discern how much of each there is," he says. So far, they've been most successful with boron introduced as borates from detergents, which are different from native boron.

Early involvement has been a key to public support for the plant, according to Balliew. Between the start of planning in 1976 and completion of the design in 1982, a citizens advisory group was established and offered different options, including direct potable reuse, desalination and ground-water importation. "They chose injection," he says.

No formal public education efforts are being conducted now, but the board "actively encourages" tours. Each year several thousand people come to the plant, many of them school groups, from elementary grades through nursing and civil engineering college students. An open house is held daily, and the department has also had a video professionally produced describing how the plant works, and its water quality aspects, Balliew says.—*JP*

the 23rd Avenue Project consists mainly of sand and gravel layers and the ground-water table is about 17 m deep (about 3 m at Flushing Meadows). The basins were operated on a schedule of two weeks flooding, two weeks drying to enhance denitrification in the soil and to allow recovery of infiltration rates between flooding periods. Infiltration rates during flooding were about 0.5 m/day, but since the basins were dry about half the time, hydraulic loading rates were about 100 m/year.

Average water quality after SAT meets the agronomic requirements for crop irrigation and California Title 22 health standards for unrestricted agricultural and urban irrigation and recreation uses. For potable use, the quality parameters needing attention are total dissolved solids (790 mg/l), total organic carbon (1.9 mg/l) and fecal coliforms (0.3/100 ml).

Pilot studies would be needed to determine the best treatment of the water after SAT for potable use. Likely treatment steps include granular activated carbon adsorption, reverse osmosis or other membrane filtration (possibly on part of the flow), and chlorination or other disinfection. As membrane technologies improve, it may become more economical to delete the carbon adsorption and use 100% membrane filtration followed by disinfection. Costs of these post-treatment schemes for a 0.4 million m^3/day plant would be about $0.23 per cubic meter for carbon filtration, reverse osmosis on half the flow and disinfection (1988 dollars). This is considerably less than the $0.60 per cubic meter cost found in Denver Water Department's reuse project for complete AWT of secondary effluent.

SAT itself is relatively inexpensive. The biggest cost is for pumping or otherwise collecting the water from the aquifer. SAT systems are also robust and fail-safe and do not require highly skilled technical personnel for operation. They offer underground storage to absorb seasonal or other differences between the wastewater supply and the demand for water after SAT, eliminating the need for surface storage facilities. Finally, SAT systems break the pipe-to-pipe connection involved in direct recycling of wastewater with in-plant treatment only—which alleviates psychological barriers against potable and other reuse of municipal wastewater.

Before municipal wastewater is used for SAT, it usually receives conventional primary and secondary treatment, though primary treatment may be sufficient. The higher organic carbon content of primary effluent may actually enhance removal of nitrogen by denitrification in the SAT system and synthetic organic compounds by stimulating greater biological activity in the soil, through increased cometabolism and secondary utilization. Satisfactory results have generally been obtained when primary effluent has been used for SAT systems. Other treatment methods prior to ground-water recharge and SAT could be lagooning, overland flow, wetlands, or similar "natural" methods.

Where SAT with infiltration systems is not feasible, because surface soils and or vadose zones are unsuitable or because aquifers have poor quality water at the top or are confined, ground-water recharge can be achieved with injection wells. However, the wastewater should then be treated to essentially drinking water standards before it goes into the well, which makes recharge through wells much more expensive than SAT.

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FROM SEWAGE FARM TO ZERO DISCHARGE

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ABSTRACT

Sewage farms and land disposal were early forms of zero discharge to keep pathogens out of surface water. Then came a period of increasingly sophisticated sewage treatment and discharge into rivers with disinfection of the river water where it was used for drinking. Presently, environmental concerns more and more call for removal of nitrogen, phosphorous, heavy metals, and toxic organic compounds before discharge into surface water. This requires expensive treatment. Another choice is reduced or zero discharge into surface water by reusing the wastewater. Water reuse is also important in water short areas, where sewage effluent is a valuable water resource. Water reuse requires treatment so that the effluent meets the quality criteria for the intended reuse. Potable use requires the most stringent treatment, but such use will mostly be a practice of last resort. Reuse typically will be non-potable (agricultural and urban irrigation, industrial, recreational), and most of these uses require tertiary treatment (coagulation, filtration, and disinfection). Soil-aquifer treatment or geopurification, as obtained with infiltration systems for groundwater recharge and complete recovery of the water from the aquifer, can play a significant role in the treatment and storage of sewage effluent for reuse.

Historic perspective

There was a time when human and other wastes were simply thrown out of the window. The only environmental concern then was a direct hit on the people in the street. Thus, as a courtesy to passersby, the thrower would yell "gardez l'eau" (watch out for the water)! This term was anglicized to gardyloo which is now the name of a British ship for ocean dumping of municipal sludge! From the streets, the waste could readily run into streams or other surface water, along with raw wastewater from the early sewers. The discovery that sewage contamination of drinking water was the main cause of disease outbreaks like cholera and typhoid then made it necessary to keep wastewater out of surface water, since adequate treatment and disinfection technology had not yet been developed. This lead to the establishment of "sewage farms" around many of the cities. Applying sewage to land rather than discharging it into surface water was an early form of zero discharge!

In the early part of this century, disinfection of drinking water by chlorination was discovered and put into use. This allowed resumption of discharging sewage into surface water, because now the surface water could be treated and disinfected for drinking, and microbiological contamination was no longer a health problem. Besides, the cities were growing and needed the sewage farms around them for more streets and houses. At the same time, better sewage treatment processes were developed and applied, primarily to prevent undue oxygen "sags" in the streams and to not exceed the "assimilative" and "self-purification" power of the receiving water. Removal of biochemical oxygen demand (BOD) and suspended solids (SS) were the main objectives. Then came the era of "better living through chemistry," causing more and more chemicals to enter sewage through discharges from households, industries, hospitals, etc. This era

was followed by increasing environmental awareness and a realization that pollution of surface water should be drastically minimized or avoided. Now, environmental concerns are calling for increasingly stringent standards for discharging sewage or other wastewater into surface water to prevent eutrophication and to protect aquatic life, recreation, and reuse opportunities of the water. For example, the U.S. Clean Water Act of 1972 calls for the elimination of all pollutant discharges into the nation's waters. Until recently, this law was not strongly enforced, but that is changing now. The trend toward more stringent regulations will undoubtedly continue until wastewater treatment becomes so expensive that municipalities will want to stop discharging their sewage effluent into surface water and use it themselves. When that happens, we have come full circle to zero discharge again! Reuse and zero discharge of wastewater are the ultimate forms of prevention of point-source pollution of surface water.

Wastewater reuse

In principle, sewage effluent and other wastewaters can be used for any purpose, provided that it is treated so that it meets the quality requirements for the intended use. Because of treatment costs and economic feasibility, however, wastewater most commonly will be used for nonpotable purposes that do not require water of a very high quality, as does drinking water. The nonpotable purposes include industrial use (power plant cooling, processing, construction, aggregate washing, dust control, etc.), toilet flushing (mostly commercial buildings but also private homes), irrigation (agricultural crops, golf courses, city parks and playgrounds, yards of private homes), recreational and decorative lakes, environmental purposes (effluent dominated streams for aquatic and riparian habitats, wetlands, wildlife refuges), and groundwater recharge.

Wetlands and similar systems often are used as treatment facilities themselves, producing an effluent that can then be reused. Potable use, while economically and technically feasible, will only be a practice of last resort, when no other water is available.

Irrigation

The necessary sewage treatment for water reuse is least for groundwater recharge with infiltration basins (see section on groundwater recharge), and for irrigation of crops not consumed by humans (tree, fiber, or seed crops) or crops cooked before human consumption (grain crops) and not brought raw into the kitchen (Bouwer and Idelovitch, 1987, Pettygrove and Asano, 1985). This is called restricted irrigation. On the other hand, unrestricted irrigation, which includes sprinkler irrigation of fruit and vegetable crops consumed raw by people and urban irrigation of parks, playgrounds, private yards, etc., requires more intensive treatment. There are now two main sets of public health water quality criteria for unrestricted irrigation with municipal wastewater. One set is for developed countries which are technically and financially capable of high technology treatment. The other is more for developing countries which cannot afford expensive treatment and where stringent health standards would lead to no treatment at all and the use of raw wastewater for unrestricted irrigation, which of course is completely unacceptable.

The standard for developed countries is patterned after California's Title 22 Effluent Reuse Standards (Bouwer and Idelovitch, 1987; Pettygrove and Asano, 1985; Shelef, 1990), and calls for treatment of wastewater so that it is essentially free from pathogenic organisms (no fecal coliforms, no viruses, no eggs of parasitic worms) and has low turbidity (less than 2 nephelometric turbidity units). This can be achieved with conventional primary and secondary

treatment followed by coagulation (sometimes followed by sedimentation), granular media filtration, and chlorination or other disinfection. Where hydrogeological conditions are favorable for groundwater recharge with infiltration basins, the movement of partially treated wastewater through soils and aquifers can clean the wastewater sufficiently so that it can be collected from the aquifer as such for unrestricted irrigation, as discussed later. The guidelines for unrestricted irrigation in mostly developing countries, as established by the World Health Organization (1989), call for a maximum fecal coliform concentration of 1000/100 ml and a maximum concentration of helminthic eggs of 1 per liter. This can be achieved by lagooning with sufficient detention times (for example, one month in warm regions). The lagoon effluent will then also have greatly reduced concentrations of bacteria and viruses.

The WHO standards are based on public health effects as manifested by documented disease outbreaks (epidemiology), and feasibility of treatment system. Case histories of disease outbreaks due to irrigation with poorly treated wastewater showed that they were mainly caused by intestinal nematodes or parasitic worms (helminthic eggs such as Ascaris and Trichuris species and hookworm, where endemic). It was also concluded that presence of pathogenic organisms in the wastewater does not necessarily mean disease outbreaks, especially if the organisms are present in sufficiently low concentrations and/or there is local immunity. On the other hand, the much more stringent California-type standards are based on avoiding presence of pathogens in the wastewater, regardless of whether they are capable of causing diseases or not, and the essentially complete elimination of such pathogens in the treatment process. This is the preferred approach where such treatment is feasible, where the public demands zero or minimum risk, and where municipalities, irrigation districts, and

farmers need to protect themselves against lawsuits in case of disease outbreaks where contaminated agricultural products are implied (Shelef, 1990). Another factor to consider is whether the crops will be entirely consumed by local people with built-up immunities to certain diseases, or whether the crops will also be consumed by outsiders (visitors to the region or people in other regions to which the crops are exported). If the crops are also consumed by outsiders, the more stringent standards should apply.

In addition to public health considerations, agronomic factors should also be considered and the wastewater should meet the normal quality requirements (salinity, sodium adsorption ratio, nitrogen, toxic and trace elements, etc.) for irrigation water (Bouwer and Idelovitch, 1987, and references therein; Pettygrove and Asano, 1985). The California-type standards also apply to most other non-potable urban uses of sewage effluent, like urban irrigation (parks, playgrounds, etc.), recreational lakes, toilet flushing, fire protection, car washing, and industrial uses. Since irrigation is mostly a consumptive use of water (most of it evaporates back to the atmosphere while the rest moves downward through the soil to underlying groundwater), and requires large quantities of water, it is an excellent way of reusing water, especially in areas with dry climates where crops and urban plantings need extra water. Worldwide, food production as a whole accounts for about 70% of the world's water use and about 17% of the world's cropland is irrigated (Postel, 1989).

Power plant cooling

Cooling water can be a major industrial use of sewage effluent. For example, all the cooling water for a modern 3810 megawatt nuclear power plant 80 km west of Phoenix, Arizona, is provided by secondary sewage effluent (activated sludge) at a flow rate of 3.2 m^3/sec. This is about one-third of the sewage flow

from a metropolitan area with about 2 million people. The effluent is treated on site (trickling filter for ammonium reduction, two-stage lime softening, dual media filtration, recarbonation, and addition of soda ash and sulfuric acid) to avoid scaling in the plant. The water then goes through a 2.7 million m^3 storage and equalization reservoir to the power plant, where it is recycled 15 to 20 times before finally being disposed of in a 196 ha evaporation pond. The rate of evaporation from a free water surface in that area is about 2 m/yr.

Soil-aquifer treatment

When wastewater after primary or secondary treatment is used for groundwater recharge with infiltration basins, the quality of the water improves significantly as it moves downward through the vadose (unsaturated) zone to the groundwater and then laterally through the aquifer to the collection system (pumped wells, gravity subsurface drains, surface drains, gaining streams, etc.). These recharge systems require permeable soils to get adequate infiltration rates, vadose zones without restricting layers or other problems (contaminated zones, undesirable chemicals that can be leached out, etc.), and aquifers that are unconfined and have good quality groundwater at the top. Infiltration basins are intermittently flooded and periodically cleaned (Bouwer, 1985 and 1990). Infiltration rates typically are on the order of a few dm/day during flooding but because of regular drying, long term average infiltration rates are more on the order of 50 to 100 m/yr. At these rates, one ha of infiltration basin can infiltrate 0.5 to 1 million m^3/yr.

When wastewater is used for groundwater recharge by surface infiltration, there are usually two objectives: (1) quality improvement of the water, and (2) seasonal or other storage in the aquifer. For these reasons, the recharge systems are designed and managed as recharge-recovery systems, using various

layouts of infiltration basins and wells, drains, or other collection facilities as shown in Figure 1 (Bouwer, 1985 and 1990). Since water quality improvement by filtration through the soil and aquifer often is the main objective, the systems are no longer called groundwater recharge systems but soil-aquifer treatment (SAT) or geopurification systems. The performance of SAT systems is site dependent and controlled by wastewater quality, soils, hydrogeology, and climate. Thus, in new areas without local SAT experience, pilot or experimental systems should always precede full-scale and operational systems so that the feasibility of SAT can be evaluated and the full-scale system can be designed and managed for optimum performance.

Examples of such experimental and demonstration projects are the Flushing Meadows Project (Bouwer *et al.*, 1980) and the 23rd Avenue Project (Bouwer and Rice, 1984) in the Salt River floodplain west of Phoenix, Arizona. Both projects used secondary effluent (activated sludge) from Phoenix. Average quality parameters for the secondary effluent as it infiltrated the soil in the basins and of the water after SAT are shown in Table 1. The metal concentrations of the effluent in this table are recent values (personal communication, Pat Wokulich, Water and Wastewater Department, City of Phoenix, 1990). Recent metal concentrations in the water after SAT were not determined. However, analyses of samples about 20 years ago indicated much higher metal concentrations in the secondary effluent and removal percentages in the SAT system of 84% for zinc, 87% for copper, 12% for cadmium, and 16% for lead (Bouwer *et al.*, 1980). Since the present metal concentrations in the wastewater, as shown in Table 1, are much lower, higher removal percentages can be expected. The vadose zone and aquifer

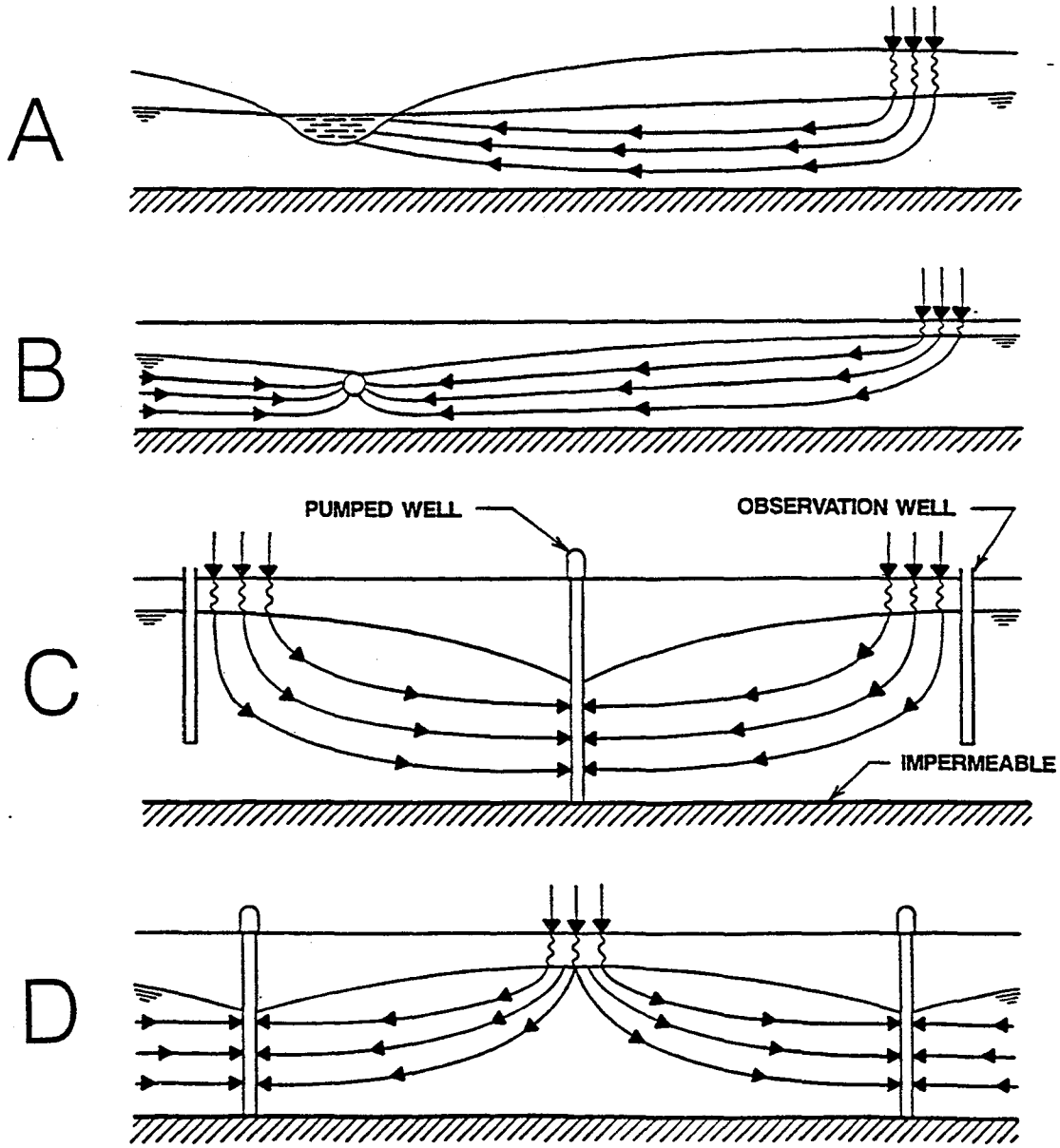

Figure 1. Schematic of soil-aquifer treatment systems with natural drainage of renovated water into stream, lake, or low area (A), collection of renovated water by subsurface drain (B), infiltration areas in two parallel rows and lines of wells midway between (C), and infiltration areas in center surrounded by a circle of wells (D).

in the 23rd Avenue Project consisted mainly of sand and gravel layers and the groundwater table was at a depth of about 17 m. There were four parallel infiltration basins totaling 16 ha. The well for pumping wastewater after SAT was located in the center of the basin area and was perforated from 30 to 55 m. The four basins of the project were operated on a schedule of two weeks flooding-two weeks drying to enhance denitrification in the soil and to allow recovery of

TABLE 1 Quality parameters from Phoenix, Arizona, SAT system for mildly chlorinated secondary effluent (activated sludge) as it entered the infiltration basins (left column) and after SAT and pumping it from a well in the center of the infiltration basin area (right column).

	Secondary effluent mg/ℓ	Recovery well samples mg/ℓ
Total dissolved solids	750	790
Suspended solids	11	1
Ammonium nitrogen	16	0.1
Nitrate nitrogen	0.5	5.3
Organic nitrogen	1.5	0.1
Phosphate phosphorus	5.5	0.4
Fluoride	1.2	0.7
Boron	0.6	0.6
Biochemical oxygen demand	12	0
Total organic carbon	12	1.9
Zinc	0.036	
Copper	0.008	
Cadmium	0.0001	
Lead	0.002	
Fecal coliforms per 100 ml	3500	0.3
Viruses, PFU/100 ℓ	2118	0

infiltration rates between flooding periods. Infiltration rates during flooding were about 0.5 m/day but since the basins were dry about half the time, hydraulic loading rates were about 100 m/yr.

The quality parameters of the water after SAT in Table 1 show that the water meets the agronomic requirements for crop irrigation and the health standards for California Title 22 effluent (Bouwer, 1985; Bouwer and Idelovitch,

1987; Pettygrove and Asano, 1985, and references therein). Hence, the water is suitable for unrestricted irrigation (including sprinkler irrigation of fruits and vegetables consumed raw or brought raw into the kitchen, and of parks and playgrounds) and for unrestricted aquatic recreation (including swimming and fishing). For potable use of the water after SAT, the quality parameters in Table 1 that need attention are total dissolved solids (790 mg/l), total organic carbon (1.9 mg/l) and fecal coliforms (0.3/100 ml). The salt concentration in the water is not excessively high, but higher than the maximum of 500 mg/l usually desired. The total organic carbon includes a wide spectrum of halogenated and non-halogenated aliphatic and aromatic compounds, many at concentrations on the order of 1 μg/l (E.J. Bouwer *et al.*, 1984). Also, the organic compounds probably include THM precursors like humic and fulvic acids. While fecal coliforms were very low and often zero, and viruses could never be detected in the water after SAT, the water should be disinfected to protect against possible breakthrough of pathogens.

Pilot studies would be needed to determine the best treatment of the water after SAT for potable use. Likely treatment steps include granular activated carbon adsorption, reverse osmosis or other membrane filtration (possibly on part of the flow), and chlorination or other disinfection. As membrane technologies continue to be improved, it may become more economical to delete the carbon adsorption and go to 100% reverse osmosis followed by disinfection. Costs (1988 U.S. dollars) of these post-treatment schemes for a 0.4 million m^3/day plant would be about \$230/1000 m^3 for carbon filtration, reverse osmosis on half the flow, and disinfection (personal communication, W. C. Lauer, 1990). The cost would increase to about \$300/1000 m^3 if the carbon adsorption is deleted and the entire flow would go through reverse osmosis followed by disinfection. SAT

itself is relatively inexpensive and the cost often consists mainly of that for pumping the water from the aquifer, if wells are used for water recovery. This is about \$5/1000 m^3 if the groundwater is shallow (about 5 m lift) and \$50/1000 m^3 if it is deep (about 50 m lift). Thus, the total cost of converting raw sewage into potable water when SAT is included in the treatment process is about \$400 per 1000 m^3 (allowing \$100 per 1000 m^3 for primary and secondary treatment).

Other advantages of groundwater recharge and SAT systems are that they are robust and fail-safe and do not require highly skilled technical personnel for operation. Also, they offer underground storage to absorb seasonal or other differences between the supply of wastewater and the demand for water after SAT. This eliminates the need for expensive surface storage facilities. Thirdly, SAT systems break the pipe-to-pipe connection of the direct recycling of wastewater with in-plant treatment only. This enhances the aesthetic aspects and public acceptance of potable reuse of municipal wastewater, because the water is pumped from wells where it has lost its identity as sewage water. This can be of great importance in countries where there are religious or sociocultural objections to the use of wastewater.

Most of the purification processes in SAT systems are renewable and sustainable, i.e., removal of suspended solids (by cleaning basin bottoms) and of microorganisms, denitrification, and biodegradation of organic compounds. Depending on pH, metals and phosphate may accumulate in the underground system (metals mostly in the upper soil layers, phosphate also in the aquifer). Rates of accumulation are very slow and dynamic equilibria may be reached. Some organic compounds may be adsorbed by organic matter and soil particles. SAT systems should have useful lives of decades and possibly centuries.

Before municipal wastewater is used for SAT, it usually receives

conventional primary and secondary treatment, at least in the United States where such treatment is required to meet discharge permit requirements. However, since SAT systems can remove a lot more BOD than is in secondary effluent, secondary treatment really is not necessary where the effluent is used for groundwater recharge and SAT. As a matter of fact, the higher organic carbon content of primary effluent actually may enhance nitrogen removal by denitrification in the SAT system (Lance *et al.*, 1980). Also, it may enhance removal of synthetic organic compounds by stimulating greater biological activity in the soil and resulting increase in co-metabolism and secondary utilization (McCarty *et al.*, 1984). Where primary effluent has been used for SAT systems, satisfactory results have generally been obtained (Carlson *et al.*, 1982; Lance *et al.*, 1980; Rice and Bouwer, 1984). Since the total cost of primary and secondary treatment in a large plant (0.4 million m^3 per day, for example) may be about $80 per 1000 m^3, elimination of the secondary treatment step would save about $40 per 1000 m^3, thus increasing the value of SAT by another $40 per 1000 m^3. This estimate is based on the assumption that the cost of primary treatment is about the same as the cost of secondary treatment. Secondary treatment requires a lot more energy and could be more expensive than primary treatment, but the cost of sludge handling and disposal in the primary treatment can also be high, depending on local conditions. Since primary effluent generally has a higher suspended solids content than secondary effluent, hydraulic loading rates of the infiltration basins may be lower and they may have to be cleaned more often. This increases the cost of SAT. SAT systems with complete recovery of the water from the aquifer, as shown in Figure 1, allow the use of the optimum combination of pre-treatment, SAT itself, and post-treatment after recovery to meet the quality requirements for the intended use of the water.

Other treatment methods prior to groundwater recharge and SAT could be lagooning, overland flow, wetlands, or similar "natural" method that is not "high-tech." Infiltration problems, however, could arise if the water from these treatment processes contains a lot of suspended algae because these can form a filter cake or clogging layer on the bottom of the infiltration basins for the SAT system. The infiltration basins then should be shallow to avoid compaction of the clogging layer and to promote rapid turnover of the water in the basins to minimize additional algae growth (Bouwer and Rice, 1989).

Potable reuse

Indirect recycling of municipal wastewater has, of course, been going on for ages along rivers that are used for both disposal of wastewater and municipal water supply. If the pollution level in such rivers is moderate, cities are giving the water essentially conventional treatment (coagulation, sedimentation, sand filtration, and disinfection) before using it for drinking. If the pollution is severe, activated carbon adsorption is included, usually as powdered activated carbon added during the flocculation-sedimentation process. Sometimes, granular activated carbon adsorption, cascade aeration, and ozonation are also used. Where stream flows and/or water quality vary, surface storage of raw water may be desirable so that water can be stored during high flows with good dilution of pollutants for use during periods of low flows or other episodes when the river water is of low quality and should be avoided. This is done by the city of Rotterdam in The Netherlands (Kuyt, 1978). Some systems use bank filtration or other groundwater recharge and recovery systems to take advantage of the quality improvement obtained when wastewater or polluted water moves through soils and aquifers (see section on soil-aquifer treatment).

Direct potable recycling requires considerable treatment (advanced

wastewater treatment or AWT) of the wastewater after conventional primary and secondary treatment. Normal drinking water standards cannot be used to determine if the water after AWT is suitable for drinking, because such standards apply only to situations where the water source is relatively unpolluted. Wastewater, however, contains many chemicals, perhaps hundreds or thousands, that enter the sewer system with residential and industrial discharges. Since it is practically impossible to develop maximum contaminant levels (MCLs) for all these chemicals in drinking water and to monitor for all these chemicals in the water after AWT, potable recycling of wastewater requires that the treatment processes be specified, rather than setting a multitude of MCLs for chemicals that may be in the product water. The AWT processes must then be tested in pilot or demonstration type projects where the suitability of the product water for drinking can be ascertained by chemical analyses, biomonitoring, and bioassays. For full-scale operations, only certain critical quality parameters (turbidity, total organic carbon, pH, fecal coliforms, etc.) then need to be monitored and biomonitoring needs to be done to make sure that the treatment processes are working correctly. Such pilot-demonstration type projects can also serve as public information centers to develop the proper community relations and to gain public acceptance. Without such acceptance, potable recycling of wastewater is not possible.

An example of a pilot/demonstration project is the Denver, Colorado, Potable Water Reuse Demonstration Project (Lauer, 1990). This project takes conventionally treated effluent (activated sludge, plus coagulation and sedimentation, and some denitrification) and converts it into drinking water with the following treatment train: lime clarification, recarbonation, granular media filtration, ultraviolet irradiation, granular activated carbon adsorption,

reverse osmosis, air stripping, ozonation, and chloramination. These steps were selected to provide the necessary treatment, redundancy, and multiple barriers against the various contaminants. For example, bacteria and viruses are removed by lime clarification, ultraviolet irradiation, reverse osmosis, ozonation and chloramination. These processes, except chloramination, also remove protozoa. Organic compounds are removed by lime clarification, activated carbon adsorption, reverse osmosis, and air stripping. Except for air stripping, these processes also remove inorganic compounds, including metals. The total costs (amortization plus operation and maintenance) of this advanced treatment in August 1988 dollars and projected to a 0.4 million m^3/day plant were about $600 per 1000 m^3 (personal communication, W. C. Lauer, 1990). To this amount must be added the costs of approximately $100 per 1000 m^3 for the primary and secondary treatment, yielding a total cost of about $700 per 1000 m^3. This is much more than the cost of approximately $400 per 1000 m^3 when SAT is included and most of the AWT processes can be eliminated.

An example of an operational AWT and recycling facility is the El Paso, Texas, Water Recycling System. This system has a capacity of about 40,000 m^3/day and presently treats about 27,000 m^3/day. The treatment train consists of primary treatment, secondary treatment (aeration) with addition of powdered activated carbon, denitrification with addition of methanol as energy source, lime clarification, recarbonation, sand filtration, ozonation, and granular activated carbon adsorption. The water is then injected through wells into an aquifer, from where it is pumped for municipal use from production wells about 3 km downgradient from the injection wells. Projected underground travel times from the injection wells to the production wells are on the order of 2 to 4 years, but may actually be shorter due to faster flow through the more permeable

layers of the aquifer. The total cost of the treatment process (excluding well injection) is about \$700/1000 m^3. Well injection, rather than groundwater recharge with infiltration basins, was selected for the El Paso project because the groundwater was relatively deep, undesirable chemicals could leach from the vadose zone, and the groundwater at the top of the aquifer was of poor quality. Thus, water after AWT was directly injected into the deeper layers of the aquifer system where the groundwater was of good quality.

Well injection

Where SAT with infiltration systems is not feasible because surface soils are unsuitable or not available, vadose zones have restricting layers or are otherwise unsuitable, or aquifers have poor quality water at the top or are confined, groundwater recharge can be achieved with injection wells. Since aquifer materials often are relatively coarse, the treatment benefits of flow of wastewater through an aquifer tend to be small. Also, to prevent clogging of the aquifer interface around the recharge well, the water should first be treated to remove all suspended solids, BOD, nutrients, and microorganisms. A residual chlorine content is also necessary to minimize bio-clogging of the well and aquifer. Thus, wastewater for well injection should be treated to essentially drinking water standards before it goes into the well. In addition, the wells should be frequently pumped and periodically redeveloped. This makes groundwater recharge through wells much more expensive than recharge with infiltration basins. However, the recharge process with wells still offers the benefits of storage in the aquifer, enhanced aesthetics and public acceptance for potable reuse of the water (no pipe-to-pipe connection), and the polishing treatment obtained in the aquifer. To maximize the latter, production wells should be a significant distance (1 km or more, for example) from injection wells to allow

for sufficient distance and time of underground travel. An example of the sequence of advanced wastewater treatment-injection wells-pumped wells is the system used by the city of El Paso, Texas, as discussed in the previous section.

Planning for water reuse

Wastewater reuse is best practiced where sewage treatment plants are relatively close to reuse areas or to existing conveyance facilities for transporting the effluent to reuse locations. This usually requires long term planning. Another approach is to build water reclamation plants on main sewer lines to treat water for local reuse projects (parks, playgrounds, golf courses, residential irrigation, toilet flushing, industrial uses, etc.). These plants typically are relatively small and they do not process sludge but return it to the sewer line for processing at the main treatment plant further down. Since the satellite plants often are in residential or populated areas, they must be "neighborhood friendly" (nice looking buildings with nice landscaping, covered tanks with special air handling systems and activated carbon filtration and/or chlorine misting of the air before returning it to the atmosphere, and underground facilities for noise control). The satellite plants typically provide primary and secondary treatment (activated sludge), and tertiary treatment consisting of coagulation, sedimentation (not always), granular media filtration, and disinfection (chlorine but also more and more ultraviolet irradiation).

Pipes, sprinklers, and other plumbing fixtures in the distribution system delivering treated sewage effluent for reuse should be clearly marked to avoid cross-connections and to make sure that the public is aware that the water is reclaimed water and should not be ingested. In southern California, purple plastic pipe is used to distribute tertiary sewage effluent for reuse.

CONCLUSIONS

Zero discharge of sewage effluent to reduce pollution of rivers or other surface water has evolved from sewage farms and land disposal systems which often were operated according to the "out of sight - out of mind" principle, to well engineered and well managed treatment plants and environmentally sound, sustainable reuse projects. Groundwater recharge and recovery systems for soil-aquifer treatment or geopurification and seasonal or other short-term storage also are increasingly used. Water reuse will become more and more important where water demands exceed water supplies, and/or where surface water quality must be protected for aquatic life or other purposes and requires essentially zero discharge of pollutants. Reuse may then be more economical than end-of-pipe treatment for meeting very stringent discharge requirements. Increasingly, end-of-pipe treatment also will be replaced by smaller up-gradient treatment plants to provide reclaimed wastewater for local reuse. There is nothing mysterious about water reuse, as long as the sewage or other wastewater is treated so that it meets the requirements for the intended use. This use may vary from agricultural and urban irrigation, recreational and environmental purposes, and cooling, processing, and other nonpotable industrial uses, to complete recycling for drinking water. Treatment requirements vary from primary treatment alone, secondary treatment, and often even tertiary treatment for nonpotable purposes, to complete advanced wastewater treatment (AWT) for potable use. Soil-aquifer treatment or geopurification can play an important role in the treatment and storage of wastewater for reuse, not only from technical and economical standpoints, but also because it enhances the aesthetics and public acceptance of water reuse. Sewage treatment technologies in the 21st century increasingly will be based on water reuse and zero discharge.

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ORANGE COUNTY PROJECTS

Martin Rigby
Orange County Water District

1:00 pm -- 1:35 pm

PROCEEDINGS

Resources, Engineering and Operations for the New Decade

ANNUAL CONFERENCE
Philadelphia, Pennsylvania
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DIRECT INJECTION OF RECYCLED WATER INTO POTABLE AQUIFERS

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INTRODUCTION

Since 1975, the Orange County Water District has operated an advanced wastewater reclamation plant, providing injection water to prevent seawater intrusion into the Huntington Beach/Fountain Valley groundwater basin and simultaneously recharge potable wells in the area. The project includes Water Factory 21 and a hydraulic barrier system consisting of 7 extraction wells and 23 multi-point injection wells with 81 injection points. Although coastal groundwater gradients fluctuate depending on recharge conditions and pumping, most of the water injected moves inland, eventually to be withdrawn by domestic and irrigation supply wells. An overview of current Water Factory 21 operations as well as a discussion of a new (Alamitos) barrier project are presented in this paper.

COASTAL INJECTION AT THE TALBERT GAP

Water Factory 21 (WF21) is operated in such a manner as to control hydraulic gradients and thus prevent seawater intrusion into the Huntington Beach/Fountain Valley area. The 3-mile wide Talbert Gap or Santa Ana Gap is at the historic mouth of the Santa Ana River and seawater can, if water pressures permit, migrate inland through the sandy, fresh water aquifer which is connected to the ocean. Brackish water can be pumped from extraction wells and returned to the ocean and fresh water pumped into the injection wells, although the extraction wells are not currently in service and have not been needed for several years. The District is currently studying the feasibility of linking these wells with a brackish water desalting facility. Figure 1 shows the general location of the extraction wells, injection wells, WF21, as well as other basin management facilities.

One of the principal reasons for building WF21 in the first place was that it provides a firm source of injection water for the seawater barrier, even in times of drought. On average, about 10 percent of the injected water moves toward the ocean, with a majority of the water traveling inland toward the main groundwater basin where it is withdrawn by domestic and irrigation supply wells. Currently, injection water for the Talbert Barrier consists of a blend of two-thirds reclaimed wastewater and one-third groundwater (pumped from a deep aquifer zone that is not subject to seawater intrusion). OCWD has applied to the Regional Water Quality Control Board for a permit to change the source of injection to a blend of 40 percent recycled water treated by activated carbon and 60 percent reclaimed water treated by reverse osmosis (RO). Under this plan, deep well water would not be injected continuously and would be used only as a supplemental supply.

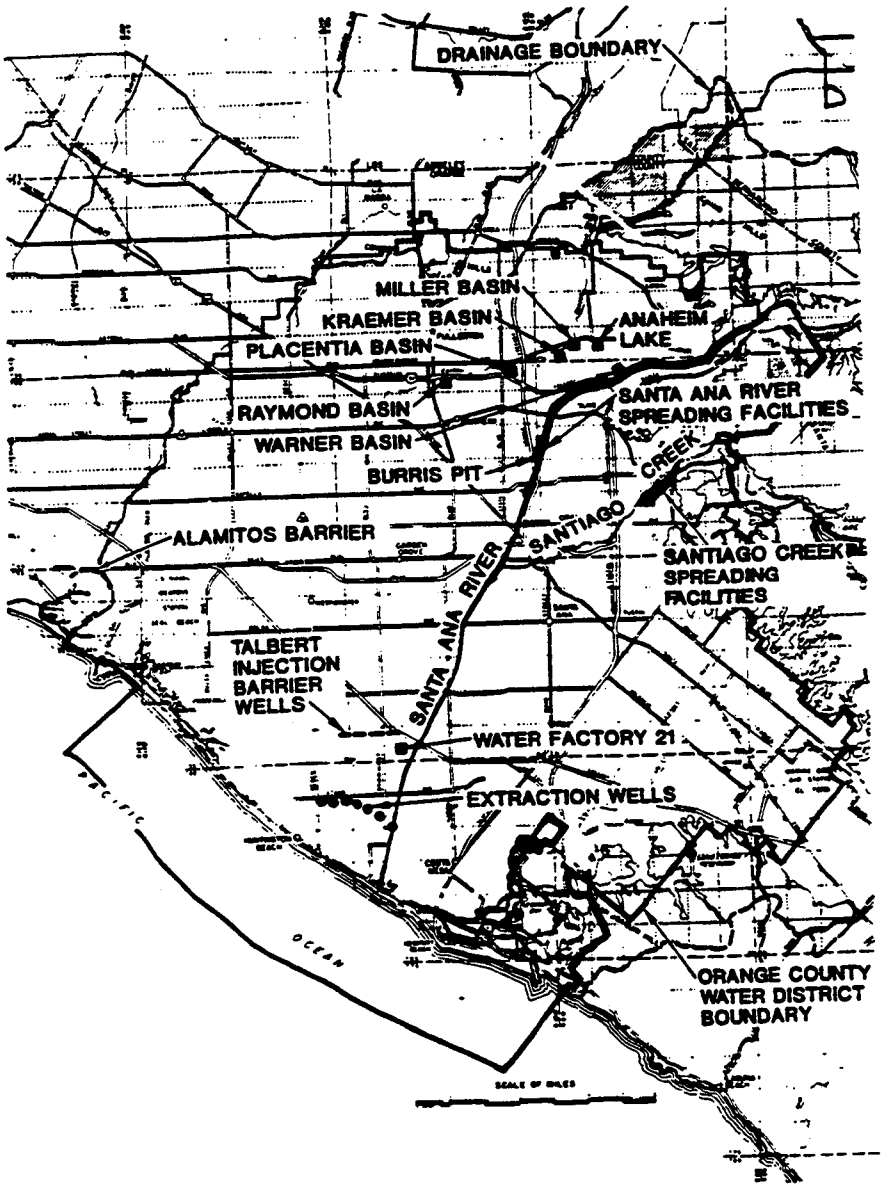

FIGURE 1

GROUNDWATER BASIN RECHARGE & SEAWATER BARRIER FACILITIES

Potable production wells currently operate as close as 1,700 feet from the injection line. Data from both production and monitoring wells show that organic material as measured by both TOC and COD is greatly reduced as the water travels through the confined aquifers. Dilution, adsorption and/or biodegradation may account for the observed removals. Water quality data from municipal, domestic, and irrigation wells in the project area show the project to have no adverse effects; organics occur at background levels.

TREATMENT PROCESSES AT WATER FACTORY 21

The following unit operations are used at WF21: lime clarification, recarbonation, mixed media filtration, activated carbon adsorption, reverse osmosis, and chlorination (Figure 2). Effluent from the carbon columns flows through the chlorine contact basin and is blended with RO treated water and groundwater before injection. There are multiple units for all treatment operations with the exception of the chlorination basin and blending reservoir. Solids from the settling basins are gravity thickened, centrifuged and incinerated in a multiple hearth furnace. Lime is recovered from the furnace and reused in the chemical clarifier. Activated carbon is regenerated on-site in a multiple hearth furnace. Brine from the RO plant is pumped to CSDOC for disposal through an ocean outfall. All components of the reclamation system and hydraulic barrier facilities have functioned well since operations began in 1975. The reclamation facilities at WF21 have consistently met all water quality requirements issued by the Regional Water Quality Control Board.

At the present time, the three sources of injection water are 1) chlorinated activated carbon effluent; 2) RO effluent; and 3) groundwater from deep (1,000 feet), high color (60 c.u.) wells.

These waters are mixed in approximately equal proportions in a blending reservoir and chlorinated again before injection. It is anticipated that the injected blend will soon change to a blend of 60 percent RO effluent and 40 percent activated carbon effluent. Current treatment processes include:

1. Chemical Clarification: Wastewater is processed through separate rapid-mix, flocculation and settling basins. Lime is the primary coagulant aided by coagulation-flocculation compounds. Lime slurry is added to the first rapid-mix basin and mechanically mixed to achieve a pH value of over 11. Sludge from the clarifier settling basins is gravity thickened, centrifuged and incinerated. The incineration process converts calcium carbonate in the lime sludge to solid calcium oxide and carbon dioxide gas. Calcium oxide is processed in a slaker and the hydrated lime reused in the chemical clarifier. Carbon dioxide from the furnace exhaust gas is used in the recarbonation process. Remaining ash and waste lime sludge is hauled to a landfill for disposal.

2. Recarbonation: The pH of the chemical clarifier effluent is lowered in a single stage recarbonation basin using carbon dioxide provided by the exhaust gases of the recalcining furnace. Purchased carbon dioxide is used occasionally when the furnace is out of operation for maintenance or repair.

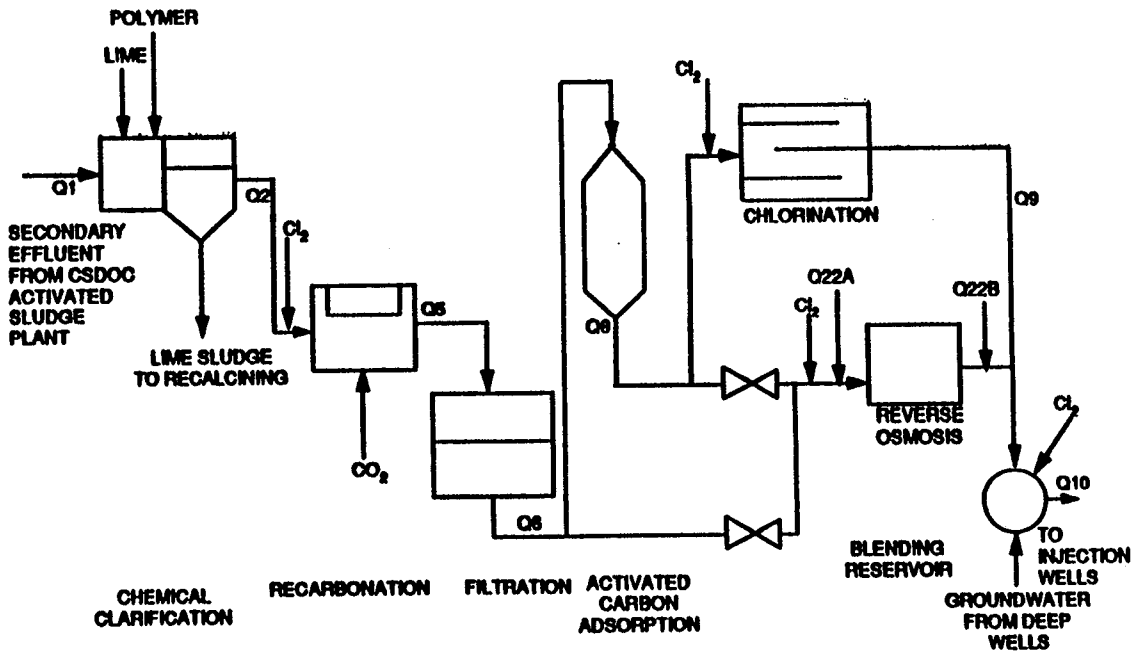

FIGURE 2
ORANGE COUNTY WATER DISTRICT
WATER FACTORY 21
FLOW SCHEMATIC & SAMPLING LOCATIONS

3. Filtration: Recarbonation basin effluent is then filtered through the following media:

Media	Depth (in.)	Specific Gravity	Grain Size (mm.)
Anthracite Coal	18	1.5	0.84-2.00
Graphite of Silica Sand	9	2.4	0.42-0.84
Garnet Sand	3	4.2	0.18-0.42

Effluent from the filters is then pumped in parallel to both activated carbon and RO facilities. Filter backwash water is retained in a surge basin and recycled to the clarification basin influent.

4. Activated Carbon Adsorption: Seventeen pressure downflow activated carbon columns operate in parallel, with contact time varying depending on the number of units in service. Exhausted carbon is thermally regenerated on-site in a multiple hearth furnace.

5. Reverse Osmosis: The RO system is designed to treat 5.0 mgd and includes high pressure pumps, cartridge filters, chemical feed, membrane units, carbon dioxide removal and brine handling. Brine from the RO system is returned to CSDOC for ocean disposal.

6. Chlorination: Effluent from the activated carbon contactors flows through the chlorine contact basin and then to the blending reservoir. Chlorine is added just upstream of the entrance to the contact basin.

7. Blending Reservoir: Effluent from the chlorine contact basin, the RO system and the deep wells is blended and stored before pumping to the injection wells. Additional chlorine is added before the blending water is injected in order to maintain a small residual in the injection wells.

INJECTION WATER QUALITY

The water treated by WF21 originates from the County Sanitation Districts of Orange County (CSDOC) Treatment Plant No. 1. CSDOC has implemented an extensive industrial waste and source control program which has resulted in the plant receiving the top award for large treatment plants in EPA Region 9 for the past 3 years. In 1989, CSDOC also received the second place national award for large secondary treatment plants, reflecting the CSDOC concern over protecting of the environment by achieving the highest water quality standards possible. A strictly enforced toxic source control program requires industries to minimize waste disposal and when possible treat wastes on site. CSDOC plans to further expand this program in the future as it develops its comprehensive wastewater management program.

Once received by OCWD, this wastewater is extensively monitored at ten key locations (see Table 1).

Table 1. WF21 WATER QUALITY MONITORING STATIONS

Monitoring Station	Location
Q1	Plant influent (secondary influent)
Q2	Chemical clarifier effluent
Q5	Recarbonation basin effluent (filter influent)
Q6	Filter effluent (carbon column and/or RO influent)
Q7	Carbon column effluent (from each column)
Q8	Combined carbon column effluent (chlorination basin influent)
Q9	Chlorination basin effluent (activated carbon treated water to blending reservoir)
Q10	Blended injection water
Q22A	RO influent
Q22B	RO effluent

The general quality of the injection water during 1990 is summarized in Table 2. As can be readily observed, effluent from WF21 consistently met all local, state, and federal drinking water standards. Many constituents, such as chloride, are consistently well below standards due to strict enforcement of basin plans by the California Regional Water Quality Control Board.

Although not regulated, TOC concentrations for the final blend injection water historically have averaged 3.0 mg/L. The injection water has consistently been free of all priority pollutants. A comprehensive study on organic removal efficiencies for various WF21 processes was completed in 1982 by Stanford University, and they are currently working with the District to further characterize organics in various OCWD product water. An enteric virus monitoring program conducted at WF21 demonstrated that treatment processes at WF21 were effective in removing viruses and parasites.

The projected quality of injection water for a blend of 60 percent RO effluent and 40 percent activated carbon effluent would also meet all requirements of the California Regional Water Quality Control Board, Santa Ana Region. With a 60/40 blend, injection water TOC concentrations are projected to average 2.3 mg/L.

Table 2. INJECTION WATER QUALITY (1990 Monthly Averages, mg/L)

Constituent	Requirement	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Sodium	115	92	78	75	66	70	92	79	44	82	88	112	106
Sulfate	125	77	61	47	38	65	66	53	9	61	87	80	74
Chloride	120	88	77	71	64	99	81	76	40	91	118	108	114
TDS	500	326	250	245	233	296	331	295	137	337	362	400	382
Hardness	180	60	46	48	42	121	62	50	12	78	73	84	72
Ph	6.5-8.5	6.9	7.0	7.1	7.2	6.9	7.2	7.0	6.9	7.2	7.1	7.1	7.1
Ammonia N	None	5.9	6.0	4.9	5.5	6.2	6.3	3.8	3.3	5.6	5.6	5.4	5.9
Nitrate N	None	0.3	0.3	0.2	0.2	0.3	1.6	0.9	2.3	1.6	0.8	1.1	0.5
Total N	10	6.6	6.3	5.4	5.7	6.7	7.8	4.7	5.6	7.6	6.5	7.1	7.3
Boron	0.5	0.4	0.4	0.4	0.4	0.3	0.4	0.3	0.1	0.4	0.4	0.3	0.4
Cyanide	0.2	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Fluoride	1.0	0.5	0.5	0.5	0.4	0.6	0.6	0.5	0.3	0.4	0.4	0.5	0.5
MBAS	0.5	0.1	0.0	0.1	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.1	0.1

GROUNDWATER QUALITY AT THE TALBERT GAP

Tracing injected water in the confined aquifers in the project area is difficult because the injection water is very similar to the native groundwater. Fluorescein dyes were used during the initial injection studies conducted in 1969, but dyes or radioactive tracers have not been used in the WF21 treatment or injection system. A study of naturally occurring radio-nucleotides conducted in the spring of 1990 was inconclusive. Chlorides can be used to trace groundwater movement, because they move conservatively in the aquifer: chlorides are not involved in sorption, chemical or biological reactions with groundwater and aquifer material. The flow weighted average concentrations of chloride are used to track groundwater quality changes near the injection wells. Studies of chloride trends indicate that injected water is present at monitoring wells in the Talbert, Alpha, Lambda, and Beta aquifers.

Other water quality parameters have remained stable in monitoring wells over the past 15 years. COD, color and nitrogen have remained near background levels even at monitoring wells located within 500 feet of the injection line. It is extremely difficult to find any impact from injection on water quality at any monitoring or municipal production well near the project area.

Well 98, operated by the City of Huntington Beach, is about 1,700 feet from the western end of the injection line and is the nearest potable supply well. Chlorides have increased from 35 mg/L in 1974 to 90 mg/L in 1990, reflecting the influence of injection water (see Table 2). TOC values have remained at background levels, indicating that although recycled water has reached this well, TOC has been effectively removed.

Well 98 was one of the wells used in the key well monitoring program in the basin and a considerable amount of data has been collected there. Most organic compounds are below detectable levels, and all organic and inorganic chemicals are within drinking water standards. Water quality data from the other municipal, domestic and irrigation wells in the project area also show no adverse effects from injected water. All data show concentration of organics unchanged at background levels.

One explanation for the consistently positive results is that no inadequately treated recycled water has been injected since the inception of the project in 1976. Because seawater intrusion occurs slowly over a period of time, it is not necessary to operate WF21 or the injection wells 100 percent of the time. Operation of the treatment facilities are suspended once a year for routine maintenance, and operation of the injection system is suspended as required for maintenance of the transmission pipeline and the injection wells. In the case of a plant upset, water being treated at WF21 can be diverted at several points in the system and returned to CSDOC Treatment Plant No. 1.

FIFTEEN YEARS OF DIRECT INJECTION: A SUMMARY

The OCWD Water Reclamation and Seawater Barrier Project has been in operation since 1975. The summary conclusions presented below are based on experience and data collected during the 15 years of operation and on the recent geological investigations and water quality modeling conducted by the District.

1. Water injected throughout the 15 years of operation has consistently met all requirements of the discharge permit issued by the California Regional Water Quality Control Board, Santa Ana Region.

2. The proposed substitution of deep well blend water with a 60/40 (RO/carbon) blend of recycled water would produce lower TOC values than those produced by current operations.

3. The injection water has not caused any drinking water standards to be violated at any of the monitoring wells or nearby potable supply wells.

4. Injected water is difficult to trace because it is chemically similar to the native groundwater.

5. The quality of injected water is improved as it travels through the confined aquifer system. Data from the monitoring wells shows that organic material as measured by both TOC and COD is greatly reduced in the confined aquifers. Research is needed to determine the mechanisms that account for the observed removals.

6. Under normal basin operating conditions, a majority of the injected water moves inland toward the main part of the groundwater basin. Several nearby domestic wells receive injected water. The direction of injected water movement and travel times are affected by hydraulic conditions in the basin. Travel time to the nearest municipal well is estimated to be on the order of 3 years. Water withdrawn at the nearest municipal well, or any other well affected by injection, will be a blend of water injected at various times and native groundwater. Composition of the blend will depend on groundwater conditions and pumping activity in the basin.

7. The basis for any TOC limitations should be reviewed, in view of the operating experience and the observed effects on groundwater quality in the project area.

8. In recognition of health and regulatory concerns over individual TOC constituents, OCWD has established an expanded research and monitoring program aimed at characterizing organics in the saturated zone influenced by WF21 injection operations.

THE NEXT THREE YEARS

OCWD, in cooperation with Central and West Basin Water Replenishment District, City of Long Beach, Los Angeles County Department of Public Works, Los Angeles County Sanitation Districts, and Metropolitan Water District of Southern California, has completed a feasibility study for a second advanced wastewater treatment facility at the Alamitos Gap, located several miles inland on the Orange/Los Angeles county line (Figure 3). The geology in this area (Figure 4) is similar to the Talbert Gap area in that underground pathways exist for movement of seawater into potable supplies. An injection system using imported domestic water supplies is currently in place to prevent seawater intrusion. The project envisioned would replace the imported supply with highly treated recycled water. High quality tertiary water

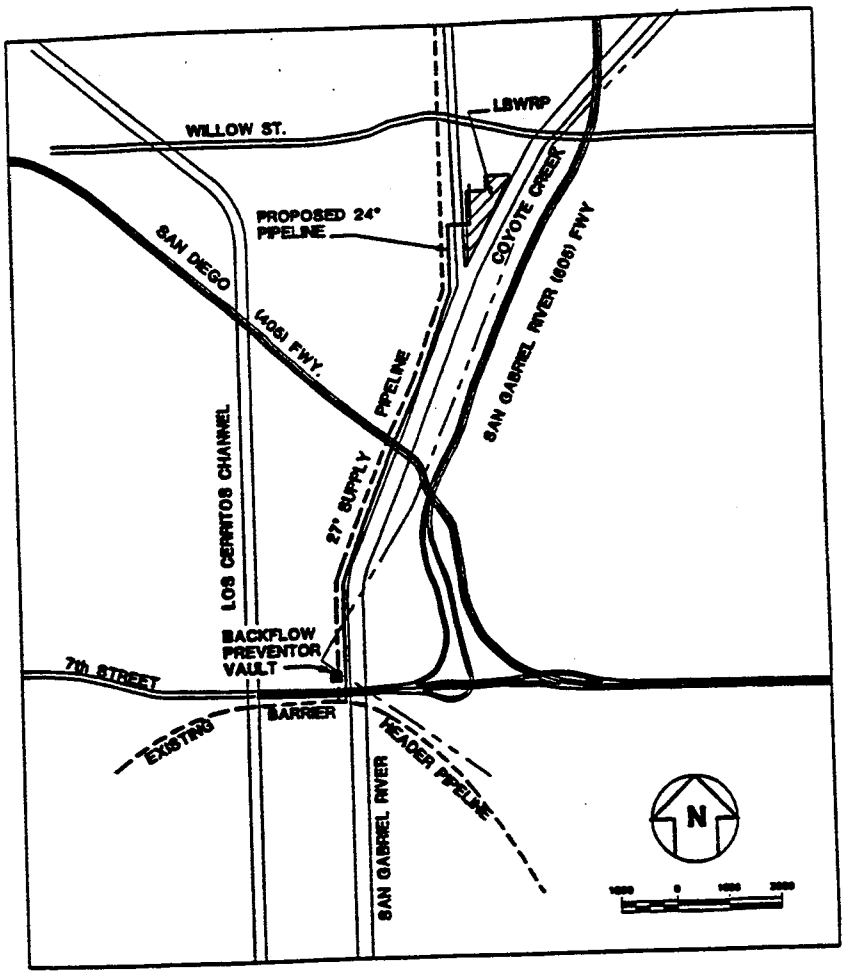
WILLOW ST.
LBWRP
PROPOSED 24"
PIPELINE
COYOTE CREEK
SAN DIEGO
(405) FWY.
SAN GABRIEL RIVER (605) FWY
PIPELINE
27" SUPPLY
LOS CERRITOS CHANNEL
BACKFLOW
PREVENTOR
VAULT
7th STREET
BARRIER
EXISTING
HEADER PIPELINE
SAN GABRIEL RIVER
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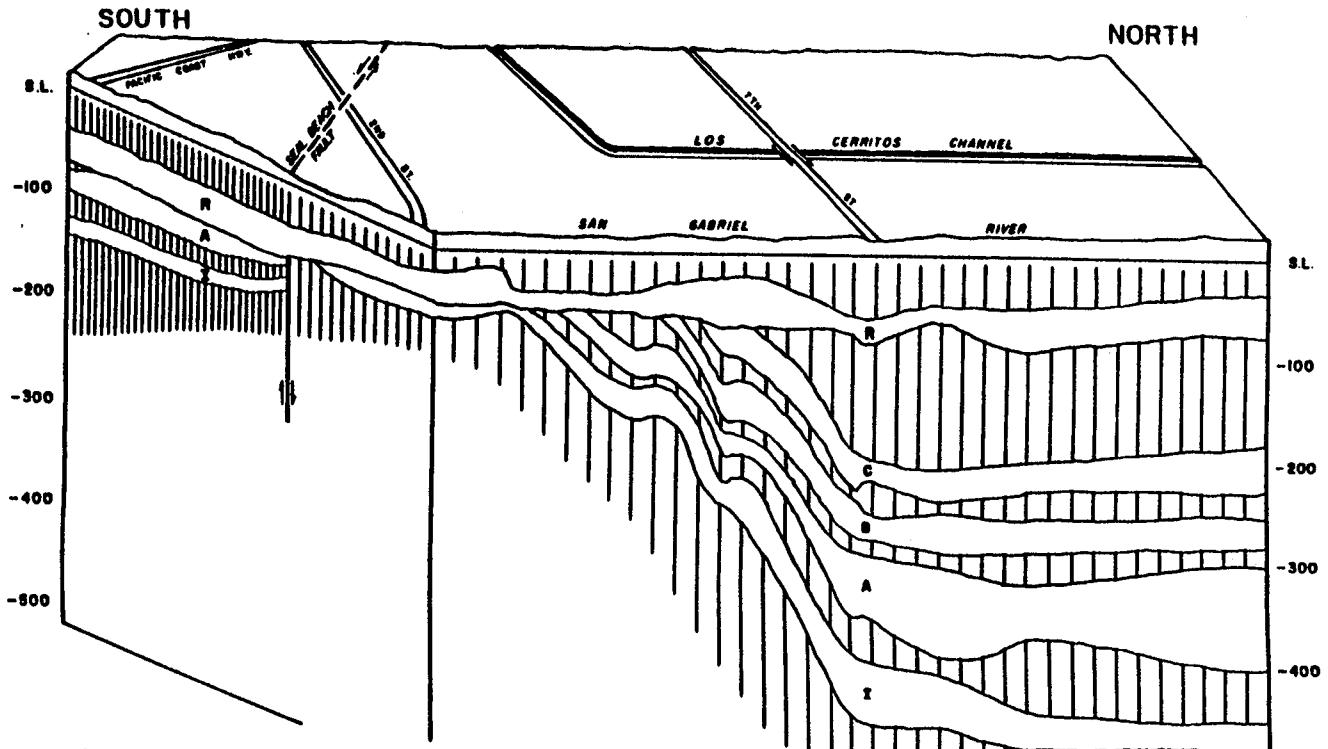
FIGURE 3



GEOLOGIC CROSS SECTION
ALONG THE SAN GABRIEL RIVER
HORIZONTAL SCALE — SCHEMATIC

FIGURE 4

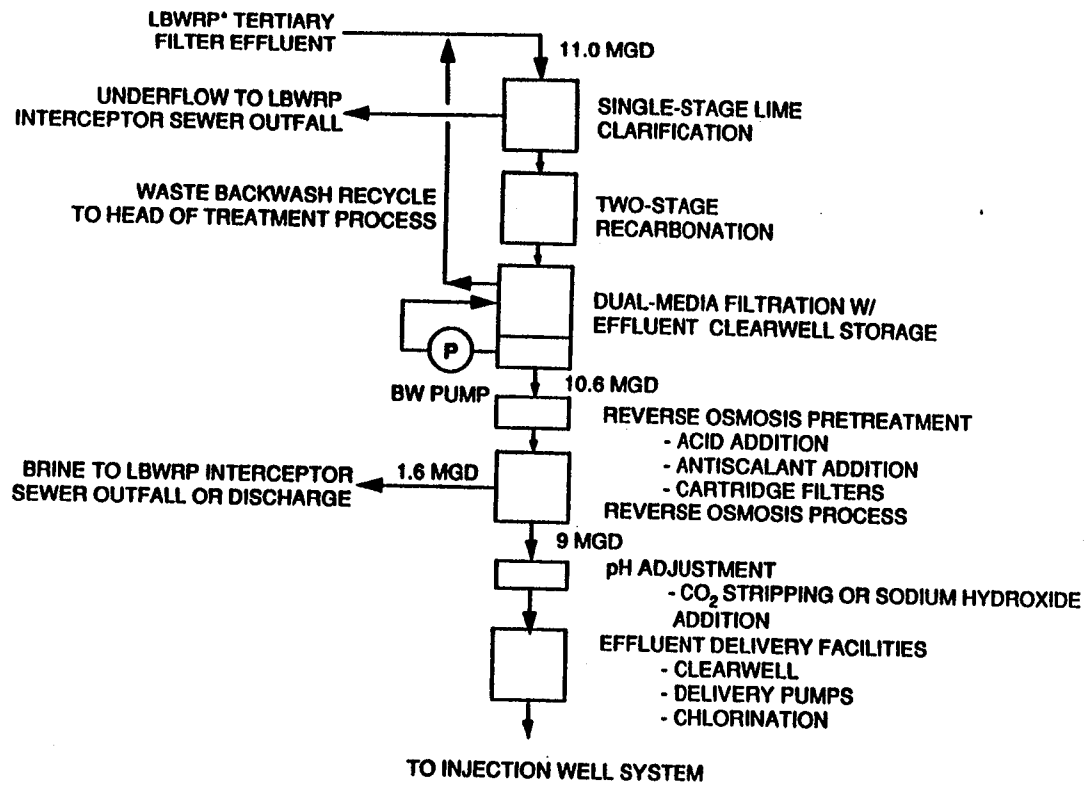
(Table 3) is currently available from the nearby Long Beach Water Reclamation Plant operated by the County Sanitation Districts of Los Angeles County. This water would then be treated by a series of processes (Figure 5) similar to those utilized at WF21. Deemed feasible by local and state agencies, funding options are currently being reviewed prior to launching into full design. It is the desire of all agencies involved to have the plant fully operational by 1994.

Table 3. ALAMITOS BARRIER PROJECT FEEDWATER QUALITY
(from Long Beach Reclamation Plant)

Constituent	Monthly Mean mg/L	Monthly Minimum mg/L	Monthly Maximum mg/L
Suspended Solids (SS)	<2	<1	3
Chemical Oxygen Demand (COD)	35	28	42
5-Day Biochemical Oxygen Demand (BOD)	8	3	16
pH	7.31	7.19	7.46
Oil & Grease	<1.1	<1.0	3.2
Nitrogen (N)	15.7	12.2	19.9
Turbidity (Nu)	1.6	1.0	2.0
Total Dissolved Solids (TDS)	611	547	660
Chloride	122	101	145
Sulfate	117	51	157
Total Organic Carbon (TOC)	12.1	10	19

Millions of dollars have been spent studying all aspects of the injection project known as Water Factory 21. These studies were recently summarized for health and regulatory officials in conjunction with an application by OCWD to increase the percent of treated wastewater in the injection water to 100 percent. Although the data collected to date does not point to any specific problem areas, the District shares the desire of health and regulatory officials to further characterize the nature of the organic carbon present in both potable and non-potable water supplies.

Toward this end, the District has entered into a contract with Stanford University to characterize TOC in both potable and non-potable supplies. Sample processing was initiated in the spring of 1991, with an initial report due out by the fall of 1991. Organic monitoring programs have also been greatly expanded. OCWD, in cooperation with the previously listed agencies, plans to design and construct a new advanced wastewater treatment facility at the Alamitos Gap. The District believes



* LONG BEACH WASTEWATER RECLAMATION PLANT

FIGURE 5. PROJECTED TREATMENT PROCESS FOR FULLSCALE ALAMITOS BARRIER ADVANCED WASTEWATER TREATMENT PLANT

that current technologies can be applied to waters of wastewater origin for the production of high quality water for direct injection into potable aquifers.

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STATE OF CALIFORNIA

PETE WILSON, *Governor*

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
SANTA ANA REGION
3010 IOWA AVENUE, SUITE 100
RIVERSIDE, CA 92507-2409
PHONE: (714) 782-4130

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O.C.W.D.

November 20, 1991

William R. Mills, General Manager
Orange County Water District
P.O. Box 8300
Fountain Valley, CA 92728-8300

TRANSMITTAL OF ADOPTED ORDER

Dear Mr. Mills:

Enclosed is a certified copy of Order No. 91-121, which revises Order No. 86-76, waste discharge requirements for Water Reclamation and Sea Water Intrusion Barrier Project.

These requirements were adopted by the Board at the November 15, 1991 meeting.

Sincerely,

Gerard J. Thibeault
Executive Officer

Enclosure: Order No. 91-121
cc: w/enclosure: State Water Resources Control Board, Division of Water Quality - Archie Mathews

aea/ocwd.fin

OCWD DISTRIBUTION	
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California Regional Water Quality Control Board
Santa Ana Region

November 15, 1991

STAFF REPORT

ITEM: 7

SUBJECT: Waste Discharge Requirements for Orange County Water District (OCWD), Water Reclamation and Seawater Intrusion Barrier Project, Orange County, Order No. 91-121

DISCUSSION:

Orange County Water District filed a complete Report of Waste Discharge for revision of waste discharge requirements for its seawater barrier project. The discharge is currently regulated under Order No. 86-76, adopted by the Regional Board on May 9, 1986.

OCWD presently accepts up to 15 million gallons per day (MGD) of secondary treated municipal wastewater from the County Sanitation Districts of Orange County's (CSDOC) Fountain Valley plant for advanced treatment at Water Factory 21, located at 10500 Ellis Avenue in the City of Fountain Valley. Water Factory 21 utilizes tertiary treatment, and activated carbon adsorption and reverse osmosis to produce a high quality reclaimed water. This reclaimed water is then blended with groundwater from deep wells for injection into the seawater barrier system. The seawater barrier system consists of a series of 23 injection wells located along Ellis Avenue in the City of Fountain Valley.

At the present time, the ratio of blended injection water consists of approximately 1/3 activated carbon treated effluent, 1/3 reverse osmosis treated effluent, and 1/3 groundwater from deep wells. OCWD is proposing to eliminate the use of groundwater and use only reclaimed water from Water Factory 21. The proposed ratio of injection water would be at least 75 percent (3/4) reverse osmosis treated and 25 percent (1/4) activated carbon treated reclaimed water.

Because the proposed recharge project involves the injection of up to 100 percent reclaimed water and is therefore substantially different from the project evaluated by the State Department of Health Services at a public hearing in 1971, the Department and the Regional Board held a joint public hearing on July 24, 1990, to evaluate the impact of the proposed injection project on the groundwater basin which is a source of domestic water supply.

Based on testimony presented at that hearing and information gathered by the Department in followup to the hearing, the Department of Health Services on September 30, 1991, made the finding that "... the proposed operation of the OCWD WF-21/Talbert Barrier project as an ongoing research and demonstration project will not impair the quality of water in the receiving aquifers as a source of domestic water supply...", subject to several conditions. The conditions recommended by the Department of Health Services have been incorporated into the the proposed waste discharge requirements, Order No. 91-121, for the Orange County Water District Water Reclamation and Seawater Intrusion Barrier Project.

The injection wells overlie the Santa Ana Pressure Groundwater Subbasin, the beneficial uses of which include, municipal and domestic supply, agricultural supply, industrial service supply, and industrial process supply.

The limitations contained in the proposed order are intended to maintain groundwater quality in the area and protect beneficial uses of the groundwater subbasin. Since domestic supply is a beneficial use, limitations are based on State Department of Health Services Primary and Secondary Drinking Water Standards, along with current Basin Plan objectives. The proposed limits on total filtrable residue, total hardness, sulfate, sodium, and chloride are also based on a "best efforts" approach, as defined by the State Water Resources Control Board.

These requirements should be adequate to protect the beneficial uses of the receiving waters of the area.

RECOMMENDATION:

Adopt Order No. 91-121, as presented.

In addition to the discharger, comments were solicited from the following agencies/persons.

State Water Resources Control Board - Ted Cobb, Office of the Chief Counsel
State Water Resources Control Board - Office of Water Recycling
State Department of Water Resources - Los Angeles
State Department of Health Services - Sacramento, Mike Kiado
State Department of Health Services - Sacramento, Pete Rogers
State Department of Health Services - San Bernardino, Chet Anderson
State Department of Health Services - Santa Barbara, Tim Gannon
State Department of Health Services - Santa Ana, Frank Hamamura
Orange County Environmental Management Agency, Environmental Resources Division
Orange County Health Care Agency - Robert Merryman
County Sanitation Districts of Orange County - Blake Anderson
City of Fountain Valley - City Manager

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
SANTA ANA REGION

ORDER NO. 91-121

Waste Discharge Requirements
for
Orange County Water District
Water Reclamation and Seawater Intrusion Barrier Project
Orange County

The California Regional Water Quality Control Board, Santa Ana Region (hereinafter Regional Board), finds that:

1. On February 22, 1990, Orange County Water District (hereinafter discharger) submitted a complete Report of Waste Discharge for revision of waste discharge requirements for the injection of blended reclaimed water into a seawater intrusion barrier and groundwater recharge system.

2. Order No. 86-76, adopted by the Regional Board on May 9, 1986, prescribed discharge requirements for the project.

3. The discharger accepts up to 15.0 million gallons per day (MGD) of secondary treated municipal wastewater from the County Sanitation Districts of Orange County (CSDOC), Fountain Valley Plant, for advanced treatment at the discharger's Water Factory 21. Water Factory 21 is located at 10500 Ellis Avenue in the City of Fountain Valley, Orange County, as shown in Attachment A, which is hereby made a part of this order.

4. The advanced treatment consists of lime clarification, recarbonation, mixed media filtration, activated carbon adsorption and chlorination. Approximately 5 MGD of the effluent from the mixed media filtration is treated by reverse osmosis. The reclaimed water is then blended with groundwater from deep wells for injection into the seawater barrier system. A flow diagram of the treatment system at Water Factory 21 is shown in Attachment B, which is hereby made a part of this order.

5. The seawater intrusion barrier project is designed to prevent seawater intrusion into the fresh water aquifers underlying the central coastal zone of Orange County, in an area known as the Talbert Gap. The seawater barrier system consists of 23 specially-designed injection wells located along Ellis Avenue between Beach Boulevard and the Santa Ana River in the Fountain Valley area of Orange County. These wells are located in Section 36, T5S, R11W, and Sections 31 and 32, T5S, R10W, SBB&M, as shown in Attachment C, which is hereby made a part of this order.

6. The current ratio of blended injection water is approximately 1/3 carbon treated effluent, 1/3 reverse osmosis treated effluent and 1/3 groundwater. The discharger is proposing to eliminate use of groundwater and use only reclaimed water from Water Factory 21 for injection.

7. The proposed blended injection water ratio will be at least 75 percent reverse osmosis treated effluent and 25 percent activated carbon treated effluent. Discharge rates into the seawater barrier injection system will increase to a maximum of 18 MGD reclaimed water and up to 25 MGD total flow if deep groundwater is used.

8. The multiple casing in the injection wells help injection of the blended water into four different aquifers known as Talbert, Alpha, Beta, and Lambda aquifers (see Attachment D). The effects of injection on groundwater pressure and quality are monitored by multiple casing observation wells (monitoring wells) similar to the injection wells.

9. The injection well sites overlie the Santa Ana Pressure Groundwater Subbasin, the beneficial uses of which include:

   a. Municipal and domestic supply,
   b. Agricultural supply,
   c. Industrial service supply, and
   d. Industrial process supply.

10. A Water Quality Control Plan (Basin Plan) was adopted by the Regional Board on May 13, 1983. The Basin Plan contains water quality objectives and beneficial uses of waters in the Santa Ana Region. On July 14, 1989, the Regional Board adopted a Basin Plan Amendment which included a revised table of beneficial use designations for waters of the region.

11. The requirements contained in this order are necessary to implement the Basin Plan.

12. On April 18, 1990, Orange County Water District adopted a negative declaration for this project in compliance with the California Environmental Quality Act (CEQA). Regional Board staff reviewed the initial study and the negative declaration and found that the project should not have significant impact on water quality if conducted within the requirements of this order.

13. On June 4, 1971, the State Department of Health Services found "...that the Orange County Water District's proposed recharge will not impair the quality of water in the receiving aquifers as a source of domestic water supply..." The State Department of Health Services made this finding under authority of Section 4458 of the California Health and Safety Code and Sections 13540 and 13541 of the California Water Code.

14. Because the proposed recharge project is substantially different from the project evaluated by the Department of Health Services in 1971, the Department and the Regional Board held a new joint public hearing on July 24, 1990, to evaluate the impact of the proposed injection of up to 100 percent reclaimed wastewater on the groundwater basin as a source of domestic water supply.

15. On September 30, 1991, the State Department of Health Services made the finding that "...the proposed operation of the OCWD WF-21/Talbert Barrier project as an ongoing research and demonstration project will not impair the quality of water in the receiving aquifers as a source of domestic water supply...", subject to several conditions. The findings and conditions recommended by the Department of Health Services are outlined in a Summary of Public Hearing and is hereby made a part of this order as Attachment E. The recommendations of the Department have been incorporated as provisions of this order.

16. The Regional Board consulted with the State Department of Health Services regarding the proposed recharge project and received its recommendations.

17. The Regional Board has notified the discharger and other interested persons and agencies of its intent to prescribe waste discharge requirements for the discharge and has provided them with an opportunity to submit their written views and recommendations.

18. The Regional Board, in a public hearing, heard and considered all comments pertaining to the discharge.

IT IS HEREBY ORDERED that the discharger shall comply with the following:

A. Discharge Specifications

1. The injection water shall not contain constituent concentrations in excess of the following limits:

Constituent	4-Sample Average Concentration Limit
Total Filtrable Residue	500 mg/l
Total Hardness (as $CaCO_3$)	180 "
Sulfate	125 "
Sodium	115 "
Chloride	120 "
Total Nitrogen	10 "
Fluoride	1.0 "
Boron	0.5 "

2. The injection water shall not contain constituent concentrations in excess of the following limits:

Constituent	Daily Maximum Concentration Limit
Aluminum	1.00 mg/l
Arsenic	0.05 "
Barium	1.0 "
Cadmium	0.01 "
Total Chromium	0.05 "
Cobalt	0.2 "
Copper	1.0 "
Cyanide	0.2 "
Iron	0.3 "
Lead	0.05 "
Manganese	0.05 "
Mercury	0.002 "
Selenium	0.01 "
Silver	0.05 "
Zinc	5.0 "
Methylene Blue Active Substances (MBAS)	0.5 "

3. The pH of the injection water shall be at all times within the range of 6.5 and 8.5 pH units.

4. The injection water shall not cause taste, odor, foam, or color in the groundwater.

A. Discharge Specifications - cont'd

5. Neither the treatment nor the injection of water shall cause a nuisance or pollution as defined in the California Water Code.

6. The injection of any substances in concentrations toxic to human, animal, plant, or aquatic life is prohibited.

7. The injection of saline wastes is prohibited.

8. The injection water shall at all times meet all the California primary drinking water standards. (CCR, Title 22, Drinking Water Quality and Monitoring Requirements.)

9. All reclaimed water injected shall be, at all times, an adequately disinfected, oxidized, coagulated, clarified, filtered wastewater meeting the requirements specified in the California Wastewater Reclamation Criteria, CCR, Title 22, Section 60313(b).

10. All reclaimed water injected shall receive organics removal treatment such that the Total Organic Carbon (TOC) concentration in the reclaimed water injected does not exceed 2.0 mg/l, based on the quarterly average of daily samples. This provision shall become effective when the percentage of reclaimed water injected first exceeds 67 percent.

11. The total nitrogen concentration in the reclaimed water injected shall not exceed 10 mg/l, based on the monthly average of at least weekly samples.

12. The maximum amount of water injected in the Talbert Barrier project shall not exceed 25 MGD, of which the maximum amount of reclaimed water shall not exceed 18 MGD, based on the quarterly average flow.

B. Provisions

1. The discharger shall comply with Monitoring and Reporting Program No. 91-121.

2. The discharger shall comply with the attached "Standard Provisions and Reporting Requirements".

B. Provisions - cont'd

3. Compliance with Discharge Specification A.1. shall be based on the flow-weighted average of the analytical results for any four (4) consecutive samples.

4. Compliance with Discharge Specifications A.2, and 3 shall be based on the analytical results for each sample.

5. The discharger shall submit a draft operating plan to the Department of Health Services and the Regional Board at the 50 percent design stage for the new treatment facilities, specifying the design and operating parameters for the treatment facilities necessary to meet the water quality requirements for injection of 100 percent reclaimed wastewater.

6. The discharger shall submit a final operating plan, for approval by the Department of Health Services and the Regional Board, covering critical operational parameters in each treatment process of the reclamation facilities. The percentage of reclaimed water injected by this project shall not be increased above the 67 percent previously authorized until 60 days after approval of the operating plan by the Department of Health Services and the Regional Board. Changes to the approved operating plan shall be made only with the approval of the Department of Health Services and the Regional Board.

7. The discharger shall at all times operate the treatment facilities in accord with the approved operating plan. Significant changes in the operation of any of the treatment processes shall be approved by the Department of Health Services and the Regional Board.

8. Consistent with the Department of Health Services designation of this proposed discharge as a research and demonstration project, the discharger shall develop and implement a plan of study, acceptable to the Department and the Regional Board, to determine the effects of injecting 100 percent reclaimed water and the fate and mechanisms of removal of contaminants of potential health concern, including TOC. The plan shall be approved at least 60 days prior to the use of more than 67 percent reclaimed water for injection. The study shall include the construction of additional monitoring wells at intervals between injection wells and extraction wells. The plan of study shall also address the following issues: characterization of TOC, special water quality monitoring, and tracing movement of reclaimed water. The potential impacts on groundwater quality from using

B. 8. cont'd

chlorinated deep well water with high organic content for blending with reclaimed water shall be evaluated as part of the study. Changes to the approved plan of study must be approved by the Regional Board and the Department of Health Services.

9. The discharger shall adopt an ordinance or resolution which effectively prevents construction of new domestic water supply wells within 2000 feet of the injection wells. This ordinance or resolution shall be adopted no later than 60 days prior to increasing the reclaimed water injected above 67 percent.

10. The discharger shall monitor domestic water supply wells in the vicinity of the injection barrier and shall immediately provide an alternate safe water supply approved by the Department of Health Services/Office of Drinking Water, if a domestic water supply well is adversely affected as a safe, wholesome and potable source of drinking water.

11. The discharger shall submit an annual report of findings prepared by a Qualified Engineer regarding the operation of the WF-21 facilities and the Talbert Barrier and the results of the monitoring and investigations of the impacts of the injection operation.

12. Order No. 86-76 is hereby rescinded.

I, Gerard J. Thibeault, Executive Officer, do hereby certify that the foregoing is a full, true, and correct copy of an order adopted by the California Regional Water Quality Control Board, Santa Ana Region, on November 15, 1991.

Gerard J. Thibeault
Executive Officer

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
SANTA ANA REGION

STANDARD PROVISIONS AND REPORTING REQUIREMENTS

A. General Provisions

1. The provisions of this order are severable, and if any provision of this order, or the application of any provisions of this order to any circumstance, is held invalid, the application of such provision to other circumstances, and the remainder of this order shall not be affected thereby.

2. This order may be modified, revoked and reissued, or terminated for cause. The filing of a request by the discharger for modification, revocation and reissuance, or termination of this order or a notification of planned changes or anticipated noncompliance does not stay any permit condition.

3. This order does not convey any property rights of any sort, or any exclusive privilege.

4. In the event of any change in control or ownership of land or waste discharge facility presently owned or controlled by the discharger, the discharger shall notify the succeeding owner or operator of the existence of this order by letter, a copy of which shall be forwarded to this Board.

5. This order is not transferable to any person except after notice to the Regional Board. The Regional Board may require modification or revocation and reissuance of this order to change the name of the discharger and incorporate such other requirements as may be necessary.

6. It shall not be a defense for a discharger in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with the conditions of this order.

7. The Regional Board, and other authorized representatives shall be allowed:

   (a) Entry upon premises where a regulated facility or activity is located or conducted, or where records are kept under the conditions of this order;

   (b) Access to copy any records that are kept under the conditions of the order;

(c) To inspect any facility, equipment (including monitoring and control equipment), practices, or operations regulated or required under this order; and

(d) To photograph, sample and monitor for the purpose of assuring compliance with this order, or as otherwise authorized by the Clean Water Act.

8. The discharger shall take all reasonable steps to minimize or prevent any discharge that has a reasonable likelihood of adversely affecting human health or the environment.

9. The discharger shall take all reasonable steps to minimize any adverse impact to receiving waters resulting from noncompliance with any effluent limitations specified in this order, including such accelerated or additional monitoring as necessary to determine the nature and impact of the noncomplying discharge.

10. The discharger shall, at all times, properly operate and maintain all facilities and systems of treatment and control (and related appurtenances) which are installed or used by the discharger to achieve compliance with this order. Proper operation and maintenance includes effective performance, adequate funding, adequate staffing and training, and adequate laboratory and process controls, including appropriate quality assurance procedures.

11. Bypass (the intentional diversion of waste streams from any portion of a treatment facility) is prohibited. The Regional Board may take enforcement action against the discharger for bypass unless:

(a) Bypass was unavoidable to prevent loss of life, personal injury, or severe property damage. (Severe property damage means substantial physical damage to property, damage to the treatment facilities that causes them to become inoperable, or substantial and permanent loss of natural resources that can reasonably be expected to occur in the absence
of a bypass. Severe property damage does not mean economic loss caused by delays in production.);

(b) There were no feasible alternatives to bypass, such as the use of auxiliary treatment facilities, retention of untreated waste, or maintenance during normal periods of equipment down time. This condition is not satisfied if adequate back-up equipment should have been installed in the exercise of reasonable engineering judgment to prevent a bypass that could occur during normal periods of equipment down time or preventive maintenance; and

(c) The discharger submitted a notice at least ten days in advance of the need for a bypass to the appropriate Regional Board.

The discharger may allow a bypass to occur that does not cause effluent limitations to be exceeded, but only if it is for essential maintenance to assure efficient operation. In such a case, the above bypass conditions are not applicable. The discharger shall promptly notify the Regional Board within 24 hours of each such bypass.

12. "Upset" means an exceptional incident in which there is unintentional and temporary noncompliance with permit effluent limitations because of factors beyond the reasonable control of the discharger. An upset does not include noncompliance to the extent caused by operational error, improperly designed treatment facilities, inadequate treatment facilities, lack of preventive maintenance, or careless or improper action. A discharger that wishes to establish the affirmative defense of an upset in an action brought for non-compliance shall demonstrate, through properly signed, contemporaneous operating logs, or other relevant evidence that:

(a) an upset occurred and that the discharger can identify the cause(s) of the upset:

(b) the permitted facility was being properly operated at the time of the upset;

(c) the discharger submitted notice of the upset as required in General Reporting Provision D.8;

(d) the discharger complied with any remedial measures required under General Provision A.15.

No determination made before an action for noncompliance, such as during administrative review of claims that noncompliance was caused by an upset, is final administrative action subject to judicial review.

In any enforcement proceeding, the discharger seeking to establish the occurrence of an upset has the burden of proof.

13. Solids, sludge, filter backwash, and other pollutants removed in the treatment or control of wastewater shall be disposed of in the manner approved by the Executive Officer of the Regional Board.

14. The discharge of any radiological, chemical, or biological warfare agent or high level radiological waste is prohibited.

15. The following wastes shall not be introduced into the treatment works:

    a. Wastes which create a fire or explosion hazard in the treatment works;

    b. Wastes which will cause corrosive structural damage to treatment works, but, in no case, wastes with a pH lower than 5.0 unless the works are designed to accommodate such wastes;

    c. Solid or viscous wastes in amounts which would cause obstruction to the flow in sewers or otherwise interfere with the proper operation of the treatment works; or

    d. Wastes at a flow rate and/or pollutant discharge rate which is excessive over relatively short time periods so that there is a treatment process upset and subsequent loss of treatment efficiency.

B. Provisions for Monitoring

1. Water quality analyses shall be performed in accordance with the most recent edition of "Environmental Protection Agency Regulations on Test Procedures for the Analysis of Pollutants" promulgated by EPA (40 CFR 136). In addition, the Board, at its discretion, may specify test methods which are more sensitive than those specified in 40 CFR 136.

2. Chemical, bacteriological, and bioassay analyses shall be conducted at a laboratory certified for such analyses by the State Department of Health Services or EPA.

3. Records of monitoring information shall include:

   a. The date, exact place, and time of sampling or measurements;

   b. The individual(s) who performed the sampling or measurements;

   c. The date(s) analyses were performed;

   d. The individual(s) who performed the analyses;

   e. The analytical techniques or methods used; and

   f. The results of such analyses.

4. Sample containers, preservations, and hold time shall conform with those in 40 CFR Part 136.

5. Effluent samples shall be taken downstream of the last addition of waste to the treatment or discharge works where a representative sample may be obtained prior to mixing with the receiving waters.

6. All monitoring instruments and devices used by the discharger to fulfill the prescribed monitoring program shall be properly maintained and calibrated as necessary to ensure their continued accuracy.

7. The flow measurement system shall be calibrated at least once per year or more frequently, to ensure continued accuracy.

C. Reporting Provisions for Monitoring.

1. For every item of monitoring data where the requirements are not met, the discharger shall submit a statement of the actions undertaken or proposed which will bring the discharge into full compliance with requirements at the earliest time, and shall submit such information, in writing, within two weeks of becoming aware of noncompliance.

2. By January 30 of each year, the discharger shall submit an annual report to the Board. The report shall contain both tabular and graphical summaries of the monitoring data obtained during the previous year. In addition, the discharger shall discuss the compliance record and the corrective actions taken or planned which may be needed to bring the discharge into full compliance with the waste discharge requirements.

3. The discharger shall retain records of all monitoring information, including all sampling and analytical results, all monitoring equipment calibration and maintenance records, all original strip charts from continuous monitoring devices, all data used to complete the application for this order, and copies of all reports required by this order. The sampling and analytical records shall include the exact location, date, and time of sampling; the analyst's name, and the analytical techniques used. Such records shall be retained for a period of at least three years from the date of the sample, report, or application. This period of retention shall be extended during the course of any unresolved litigation regarding this discharge or by the request of the Board.

4. The discharger shall file with the Board technical reports on self-monitoring work performed according to the detailed specifications contained in any Monitoring and Reporting Program or as directed by the Executive Officer.

5. The results of any analysis of samples taken more frequently than required at the locations specified in the Monitoring and Reporting Program shall be reported to the Board.

6. The discharger shall submit to the Board, by January 30 of each year, an annual summary of the quantities of all chemicals listed by both trade and chemical names which are used for cooling and/or boiler water treatment and which are discharged.

D. General Reporting Provisions

1. The discharger shall submit to the Board on or before each compliance report date, a report detailing his compliance or noncompliance with the specific schedule date and task.

2. If noncompliance is being reported, the reasons for such noncompliance shall be stated plus an estimate of the date when the discharger will be in compliance. The discharger shall notify the Board by letter when compliance with the time schedule has been achieved.

3. The discharger shall file with the Board a report of waste discharge at least 120 days before making any material change or proposed change in the character, location, or volume of the discharge.

4. The discharger shall give advance notice to the Regional Board as soon as possible of any planned physical alterations or additions to the permitted facility.

5. The discharger shall give advance notice to the Regional Board of any planned changes in the permitted facility or activity that may result in noncompliance with these waste discharge requirements.

6. Noncompliance Reporting

   (a) The discharger shall report any noncompliance that may endanger health or the environment. Any information shall be provided to the Executive Officer (714-782-4130) and the Office of Emergency Services (1-800-852-7550), if appropriate, as soon as the discharger becomes aware of the circumstances. A written report shall be submitted within 5 days and shall contain a description of the noncompliance and its cause; the period of noncompliance, including exact dates and times and, if the noncompliance has not bee corrected, the anticipated time it is expected to continue; and steps taken or planned to reduce, eliminate, and prevent reoccurrence of the noncompliance.

   (b) The following shall be included as information that must be reported within 24 hours under this paragraph:

      i. Any unanticipated bypass that exceeds any effluent limitation in this order.

      ii. Any upset that exceeds any effluent limitation in this order.

      iii. Any violation of a maximum daily discharge limitation for any of the pollutants listed in this order.

(c) The Regional Board may waive the above-required written report on a case-by-case basis.

7. The discharger shall file a written report with the Board within ninety (90) days after the average dry-weather waste flow for any month equals or exceeds 75 percent of the design capacity of his waste treatment and/or disposal facilities. The discharger's senior administrative office shall sign a letter which transmits that report and certifies that the policy making body is adequately informed about it. The report shall include:

   a. Average daily flow for the month, the date on which the instantaneous peak flow occurred, the rate of that peak flow, and the total flow for the day.

   b. The discharger's best estimate of when the average daily dry-weather flow rate will equal or exceed the design capacity of his facilities.

   c. The discharger's intended schedule for studies, design, and other steps needed to provide additional capacity for this waste treatment and/or disposal facilities before the waste flow rate equals the capacity of present units. (Reference: Sections 13260, 13267(b), and 13268, California Water Code.)

8. The discharger shall file with the Board within ninety (90) days after the effective date of this order a technical report on his preventive (failsafe) and contingency (cleanup) plans for controlling accidental discharges and for minimizing the effect of such events. The technical report should:

   a. Identify the possible sources of accidental loss, untreated waste bypass, and contaminated drainage. Loading and storage areas, power outage, waste treatment outage, and failure of process equipment, tanks, and pipes should be considered.

   b. Evaluate the effectiveness of present facilities and procedures and state when they become operational. Describe facilities and procedures needed for effective preventive and contingency plans.

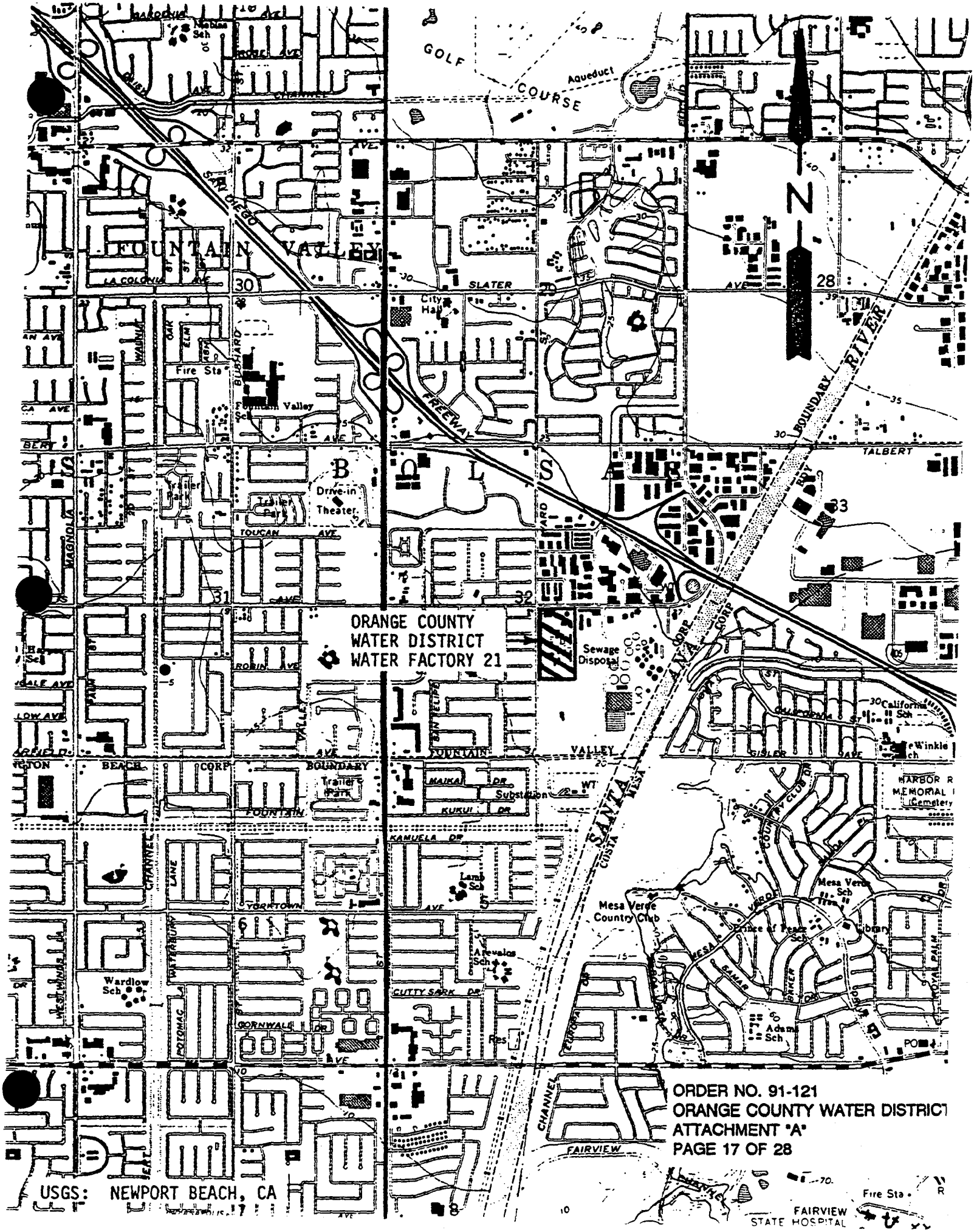
c. Predict the effectiveness of the proposed facilities and procedures and provide an implementation schedule containing interim and final dates when they will be constructed, implemented, or operational. (Reference: Sections 13267(b) and 13268, California Water Code.)

E. Definitions

1. The "maximum daily" concentration is defined as the measurement made on any single grab sample or composite sample.

2. A "grab" sample is defined as any individual sample collected in less than 15 minutes.

3. A composite sample is defined as a combination of no fewer than eight individual samples obtained over the specified sampling period. The volume of each individual sample shall be proportional to the discharge flow rate at the time of sampling. The compositing period shall equal the specific sampling period, or 24 hours, if no period is specified.



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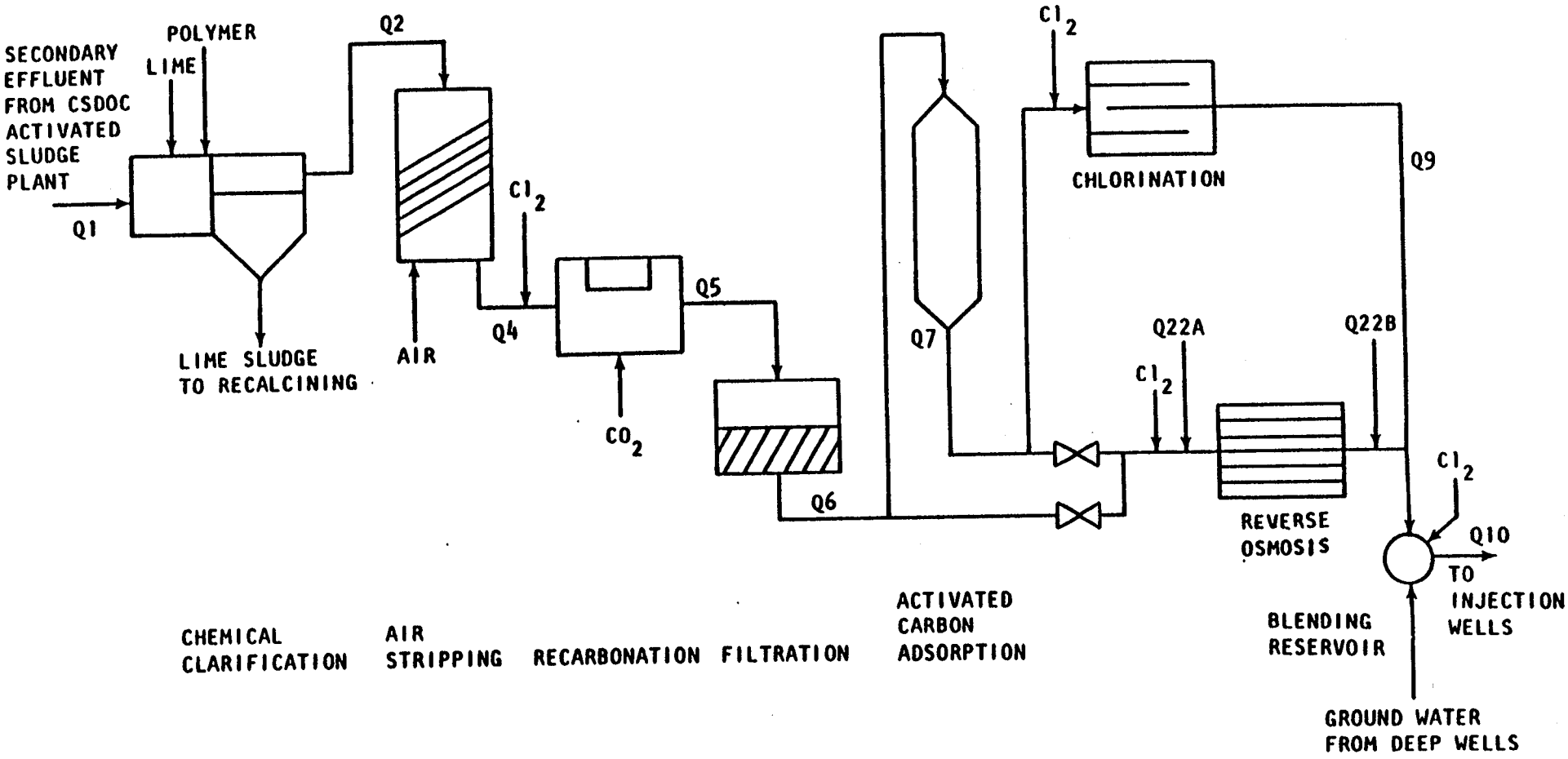
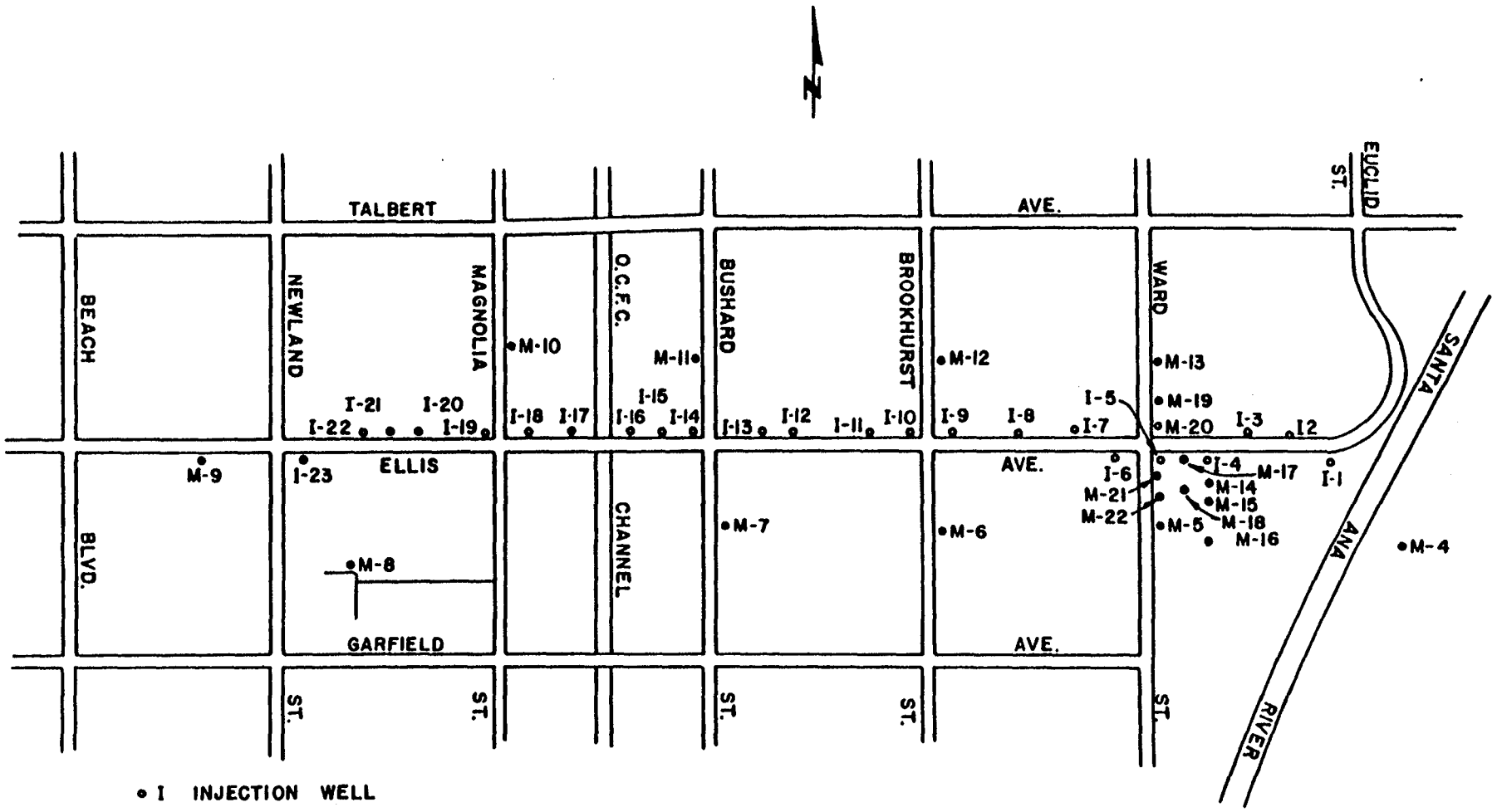


FIGURE 1

ORANGE COUNTY WATER DISTRICT WATER FACTORY 21
FLOW SCHEMATIC AND SAMPLING LOCATIONS



• I INJECTION WELL

• M OBSERVATION (MONITORING) WELL

WELL LOCATIONS

FIGURE 3

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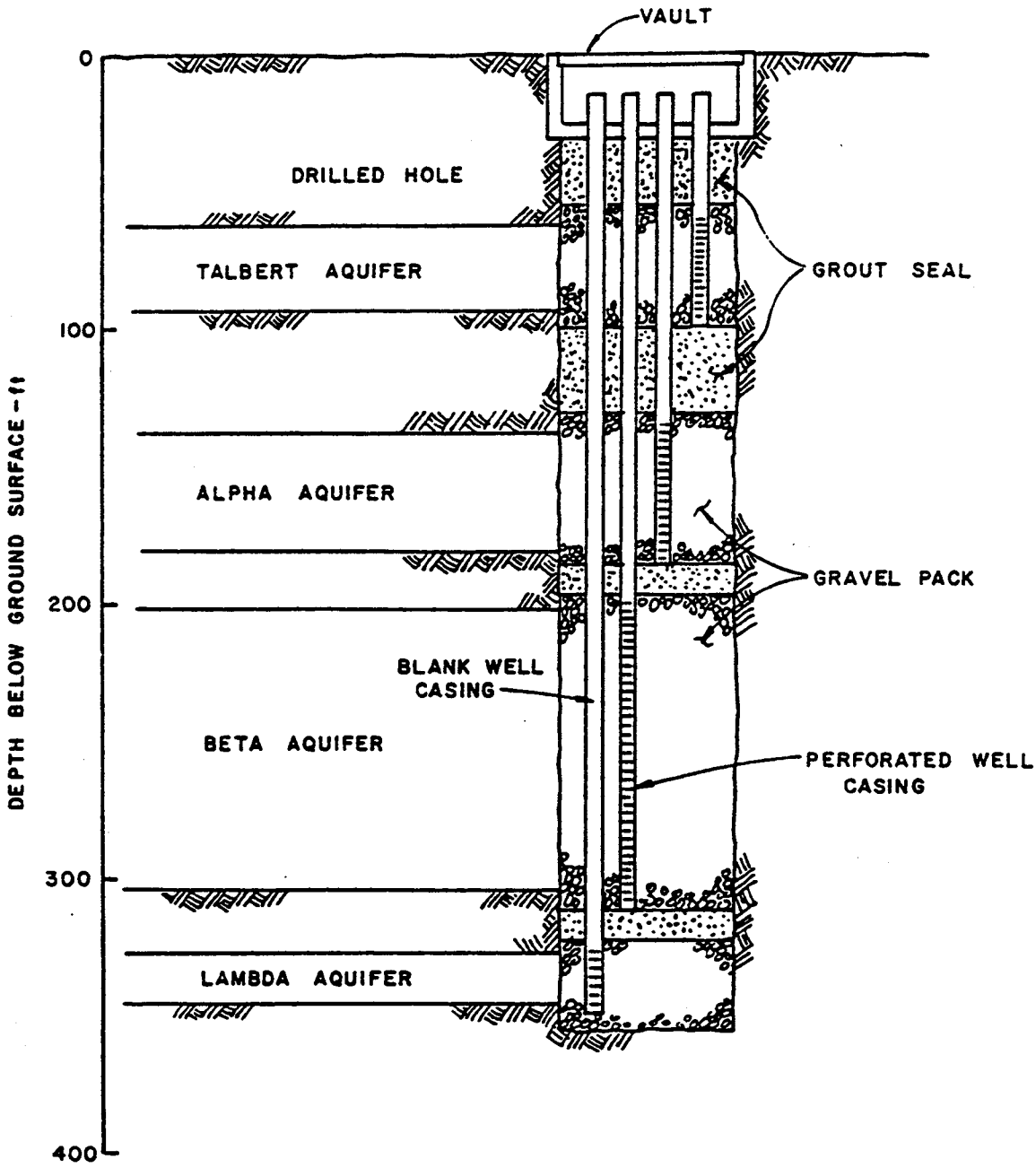

TYPICAL INJECTION OR OBSERVATION WELL

FIGURE 2

CALIFORNIA REGIONAL WATER QUALITY CONTROL BOARD
SANTA ANA REGION

Monitoring and Reporting Program No. 91-121
for
Orange County Water District
Water Reclamation and Seawater Intrusion Barrier Project
Orange County

A. Treatment Plant Influent Monitoring

1. A continuous recording device shall be installed and maintained at the point of inflow to the treatment facility to measure the electrical conductivity of all influent wastewater.

B. Reclaimed Water Monitoring

1. A sampling station shall be established and located where representative samples of the reclaimed water can be obtained. The reclaimed water shall be monitored according to the following schedule:

Constituent	Units	Type of Sample	Minimum Frequency of Analysis
Flow	MGD	----	Continuous
Turbidity	NTU	----	"
Chlorine Residual	mg/l	----	"
Total Coliform	CFU/100 ml	Grab	Daily
Total Organic Carbon	mg/l	24 hr Composite	"
Total Nitrogen	"	"	Weekly

C. Injection Water Monitoring

1. A sampling station shall be established and located where representative samples of the injection water can be obtained. The following shall constitute the injection water monitoring program:

Constituent	Units	Type of Sample	Minimum Frequency of Analysis
Flow	MGD	----	Continuous
Electrical Conductivity	micromhos/cm	----	"
Total Coliform	CFU/100 ml	Grab	Daily
pH	pH units	24 hr Composite	"
Total Organic Carbon	mg/l	"	"

C. 1. cont'd

Constituent	Units	Type of Sample	Minimum Frequency of Analysis
Total Nitrogen	mg/l	24 hr Composite	Weekly
Total Filtrable Residue	"	"	"
Total Hardness	"	"	"
Sulfate	"	"	"
Sodium	"	"	"
Chloride	"	"	"
Fluoride	"	"	"
Boron	"	"	"
Bicarbonate	"	"	"
Total Alkalinity	"	"	"
Aluminum	"	"	Monthly
Arsenic	"	"	"
Barium	"	"	"
Cadmium	"	"	"
Total Chromium	"	"	"
Cobalt	"	"	"
Copper	"	"	"
Cyanide	"	"	"
Iron	"	"	"
Lead	"	"	"
Manganese	"	"	"
Mercury	"	"	"
Selenium	"	"	"
Silver	"	"	"
Zinc	"	"	"
MBAS	"	"	"
Calcium	"	"	"
Magnesium	"	"	"
Potassium	"	"	"
Hydroxide	"	"	"
Carbonate	"	"	"
Turbidity	NTU	"	"
Radioactivity	pCi/l	"	Quarterly
Organic Chemicals*	ug/l	Grab	"
EPA Priority Pollutants Scan (See Attachment G)	"	"	Annually

* See Attachment F

2. Daily samples shall be collected on each day of the week.

3. Weekly samples shall be collected on a representative day of the week.

4. Monthly samples shall be collected on the 10th working day of the month.

5. Quarterly samples shall be collected on the 10th working day of January, April, July, and October.

6. Annual samples shall be collected on the 10th working day of October.

7. Organic chemical analyses shall be as specified by the Department of Health Services in accord with California drinking water standards (CCR Title 22, Division 5, Part 1, Chapter 15, Drinking Water Quality and Monitoring Requirements) as indicated in Attachment F.

D. Monitoring Well Sampling Program

1. Representative groundwater samples shall be collected from the Talbert, Alpha, Beta and Lambda aquifer zones, as shown in Attachment C, of monitoring wells M-9, M-10, and M-19, and shall be analyzed according to the following schedule:

Constituent	Units	Type of Sample	Minimum Frequency of Analysis
Electrical Conductivity	micromhos/cm	Grab	Monthly
Total Filtrable Residue	mg/l	"	"
Total Hardness	"	"	"
Chloride	"	"	"
Total Organic Carbon	"	"	"
Total Nitrogen	"	"	"
Fecal Coliforms	CFU/100 ml	"	"
Odor	threshold odor #	"	Quarterly
Color	color units	"	"
Sulfides	mg/l	"	"
MBAS	"	"	"
Nitrate Nitrogen	"	"	"
Nitrite Nitrogen	"	"	"
Ammonia Nitrogen	"	"	"
Kjeldahl Nitrogen	"	"	"
Sodium	"	"	"
Calcium	"	"	"
Magnesium	"	"	"
Potassium	"	"	"
Total Alkalinity	"	"	"
Hydroxide	"	"	"
Carbonate	"	"	"
Bicarbonate	"	"	"
Sulfate	"	"	"
Fluoride	"	"	"
Aluminum	"	"	"
Arsenic	"	"	"
Barium	"	"	"
Cadmium	"	"	"
Chromium	"	"	"

D. 1. cont'd

Constituent	Units	Type of Sample	Minimum Frequency of Analysis
Copper	mg/l	Grab	Quarterly
Iron	"	"	"
Lead	"	"	"
Manganese	"	"	"
Selenium	"	"	"
Silver	"	"	"
Zinc	"	"	"
Radioactivity	pCi/l	"	"
Organic Chemicals*	ug/l	"	"
EPA Priority Pollutants Scan (See Attachment G)	"	"	Annually

* See Attachment F

E. Reporting

1. Monthly monitoring reports shall be submitted by the 15th day of each month and shall include:

   a. The results of all weekly analyses,

   b. The results of all monthly analyses, and

   c. The total flow of all injection water by each source.

2. The results of the quarterly samples shall be submitted by the 15th day of March, June, September, and December.

3. If no injection or wastewater treatment occurs during the monitoring period, a statement to that effect shall be included in the monthly report.

4. All reports shall be arranged in a tabular format to clearly show compliance or noncompliance with each discharge limitation.

5. All analyses shall be conducted at a laboratory certified for such analyses by the State Department of Health Services or one approved by the Executive Officer.

6. For every item where the requirements are not met, the discharger shall submit a statement of the actions undertaken or proposed which will bring the discharge into full compliance with requirements at the earliest time and submit a timetable for correction.

7. All reports shall be signed by a responsible officer or duly authorized representative of the discharger and shall be submitted under penalty of perjury.

8. The annual report of findings prepared by a Diplomate of the American Academy of Environmental Engineers shall summarize the results of monitoring for the previous year and the status of investigations regarding the impacts of the injection operations. This annual report shall be submitted to the Regional Board and the State Department of Health Services no later than June 30th each year.

Ordered by _____
Gerard J. Thibeault
Executive Officer

November 15, 1991

Summary of Public Hearing

In the Matter of:

ORANGE COUNTY WATER DISTRICT)
WATER FACTORY 21/TALBERT BARRIER PROJECT)
PROPOSED CHANGE IN WASTEWATER)
RECLAMATION AND SEAWATER)
INTRUSION BARRIER PROJECT)

On July 24, 1990, the California Department of Health Services (DHS) and the California Regional Water Quality Control Board, Santa Ana Region (CRWQCB), held a joint public hearing in Newport Beach, California to consider a proposed change in the Orange County Water District's (OCWD) wastewater reclamation and seawater intrusion barrier project.

The hearing panel included:

Hearing Officer:
Peter A. Rogers, Chief, Office of Drinking Water, DHS

Panel Members
Anita B. Smith, Chairwoman, CRWQCB
Jerry A. King, Member, CRWQCB
Jack Leggett, Member, CRWQCB
Bill Speyers, Member, CRWQCB

An extensive presentation on the project was made by the Orange County Water District General Manager, staff, and consultants followed by questions and discussion by the hearing panel members and agency staff. There was no testimony at the hearing in opposition to the proposed project changes.

Summary minutes of the public hearing were prepared by CRWQCB staff and are available along with a complete recording of the hearing at the CRWQCB office.

FINDINGS OF FACT

1. Section 13540 of the California Water Code requires that reclaimed water may only be injected into an aquifer that is used as a source of domestic water supply if the Department of Health Services makes a finding that the recharge will not impair the quality of water in the receiving aquifer as a source of water for domestic purposes.

2. Reclaimed wastewater contains varying amounts of unidentified trace organic compounds depending on the degree of treatment applied. The long-term health effects (e.g. carcinogenicity and mutagenicity) of the unidentified organics are not known. A Scientific Advisory Panel (SAP) assembled by the State of California to evaluate the recharge of groundwater with reclaimed wastewater recommended in its 1987 report that the amount of trace organics in reclaimed wastewater used to recharge groundwater used for drinking water be limited because of health concerns.

3. In the absence of a generally accepted measure of organic compounds of potential concern, Total Organic Carbon (TOC) is considered by the Department of Health Services to be a reasonable surrogate measure of the trace organics present in wastewater after treatment.

4. The Scientific Advisory Panel indicated that reducing TOC to one mg/l or less would minimize concern about the presence of individual chemicals that could pose a threat to health. No domestic water supply well should extract groundwater with more than one mg/l TOC of wastewater origin.

5. Additional information is needed regarding the fate of organic chemicals in aquifers recharged by injection of reclaimed water, especially where a high percentage of reclaimed water may be extracted by domestic water wells. A research and demonstration project involving the injection of highly treated reclaimed water in conjunction with a thorough investigation of the impacts on the groundwater as a source of domestic water supply can help to provide the needed information.

6. The Orange County Water District (OCWD) has operated Water Factory 21 (WF-21) for over 15 years to produce reclaimed water for injection to create a seawater intrusion barrier (Talbert Barrier).

7. The failure to maintain an effective seawater intrusion barrier would cause serious water quality degradation in drinking water aquifers in Orange County and the potential loss of this water resource.

8. OCWD proposes to treat up to a maximum of 18 million gallons per day (MGD) of reclaimed water at the WF-21 facilities. The injection facilities can inject a maximum of 25 MGD. These limits are based on practical hydraulic and operational requirements. Additional reverse osmosis capacity is planned by OCWD.

9. Over the past 14 years, approximately 55 percent of the water injected into the Talbert Barrier has been highly treated reclaimed wastewater from WF-21. All of the reclaimed water has received organics removal treatment, either by reverse osmosis (RO)(58 percent average) or granular activated carbon (GAC)(42 percent average). Based on data from WF-21 during the past five years, RO reduced the TOC to less than 1 mg/l and GAC reduces TOC to less than 7 mg/l on an annual average basis.

10. The remaining 45 percent of injected water has been deep well water with high color and organic content (3 to 4 mg/l TOC annual average during the past 5 years). The TOC concentration of the combined flow (1/3 RO, 1/3 GAC and 1/3 deep well water) is currently about 3 mg/l.

11. The WF-21/Talbert Barrier operation has apparently resulted in the nearest public water supply well receiving nearly 100 percent injection water, more than half of which is reclaimed water originating from WF-21. The well is 1800 feet distant from the injection wells but the travel time is calculated to be between 2 and 4 years. The calculations of travel time were based on a maximum flow rate of injected water of 25 MGD.

12. Monitoring of the nearest public water supply well over the past five years indicates TOC concentrations of 1 mg/l or less. Observation wells close to the injection wells have been tested for TOC for only the past year. During that time, over 275 samples from the 20 nearest observation wells have been tested. The results indicate TOC concentrations of less than 1 mg/l in groundwater affected by the injection operation. These TOC levels are typical of what has been found in domestic wells throughout Orange County.

13. Extensive water quality monitoring by OCWD for the past 15 years indicates no degradation of groundwater quality by chemicals or microorganisms of public health concern. Some minerals such as chlorides have been increased in the groundwater to levels similar to the injected water, but these levels are well within acceptable limits for drinking water sources.

14. OCWD has proposed to change the operation of the Talbert Barrier project to inject up to 100% reclaimed water from WF-21 and to eliminate the requirement to inject at least 1/3 deep well water. Deep well water may continue to be used to meet barrier injection requirements.

15. The proposed change would increase the percent reclaimed water to a maximum of 100 percent. With the increase, OCWD expects it will need to treat from 75 to 90 percent of the reclaimed water by reverse osmosis in order to meet regulatory requirements for nitrogen and TOC.

16. Effective source control of toxic chemicals is provided by the County Sanitation Districts of Orange County (CSDOC) pretreatment program, which regulates the discharge of industrial wastes into the CSDOC sewage collection system. The program minimizes the risk that wastewater treated at the CSDOC Plant #1 and WF-21 will be contaminated with toxic chemicals. An effective source control program and intensive monitoring by OCWD are required to assure that the reclaimed water produced at WF-21 and injected into the groundwater in the Talbert Barrier is not contaminated with toxic chemicals of industrial origin.

17. The capability of OCWD's WF-21 treatment process to adequately reduce viruses in the reclaimed wastewater before injection has been demonstrated sufficiently. However, this capability is very dependent on the proper operation of all component treatment processes. In addition to frequent monitoring of water quality of the injected water and receiving aquifers, the safety of the groundwater recharge system depends on all components of the reclaimed water treatment being properly operated at all times. This is necessary to assure removal of such non-routinely measured constituents as pathogens (including viruses and giardia). Proper operation needs to be defined in an operating plan covering critical parameters in each treatment process. Any change in the treatment processes that could affect the removal of viruses would require virus testing to verify equivalency with the current treatment processes.

18. It is important that new drinking water extraction wells not be constructed within 2000 feet of the OCWD injection wells for protection of public health and to maintain the required barrier against seawater intrusion. An effective program to preclude construction of such wells is needed. The OCWD indicates that it can adopt a district resolution which will have the effect of prohibiting the construction of new domestic wells within a 2000 foot zone. Existing wells within this zone should be routinely monitored to detect any impairment of quality that could affect domestic uses.

19. The hydrology of the multiple aquifer groundwater basin system in the vicinity of the injection/barrier project is extremely complex. It is impacted by many variables including factors affecting the ground water basin some distance from the project. These include drought, pumping patterns and volumes, new and existing extraction projects amount of recharge, effects of extraction on the seaward side of the barrier and other factors. It is important that the effects of these factors on water quality from production wells closest to the injection wells be evaluated to determine whether water quality characteristics are attributable to soil treatment mechanisms or to dilution/movement of other water in the aquifers.

CONDITIONS

Based on the above FINDINGS OF FACT, which are made pursuant to the information submitted by the Orange County Water District in the Engineering Report on the Water Reclamation and Seawater Intrusion Barrier Project dated July 1990, the presentation by OCWD at the Public Hearing held by the California Regional Water Quality Control Board (CRWQCB), Santa Ana Region and the Department of Health Services, Office of Drinking Water (Department) in Newport Beach on July 24, 1990, and subsequent information provided to the Department by the District following the hearing, the Department of Health Services FINDS that the proposed operation of the OCWD WF-21/Talbert Barrier project as an ongoing research and demonstration project will not impair the quality of water in the receiving aquifers as a source of domestic water supply PROVIDED ALL OF THE FOLLOWING CONDITIONS ARE MET:

1. All reclaimed water injected shall be, at all times, an adequately disinfected, oxidized, coagulated, clarified, filtered wastewater meeting the requirements specified in the California Wastewater Reclamation Criteria, CCR, Title 22, Section 60313(b)

2. The injection water shall at all times meet all the California primary drinking water standards. (CCR, Title 22, Drinking Water Quality and Monitoring Requirements.)

3. The TOC in the reclaimed water injected shall not exceed 2.0 mg/l, based on the quarterly average of daily samples.

4. The total nitrogen concentration in the reclaimed water injected shall not exceed 10 mg/l, based on the monthly average of at least weekly samples.

5. An operating plan, acceptable to CRWQCB and the Department, covering critical operational parameters in each treatment process of the WF-21 reclamation facility shall be developed and submitted for approval. OCWD shall operate its facilities in accord with the approved plan. Significant changes in the operation of any of the WF-21 treatment processes shall be reported to the CRWQCB and the Department. Changes to the approved operating plan must be approved by RWQCB and the Department.

6. A comprehensive monitoring program acceptable to CRWQCB and the Department shall be developed and implemented. The monitoring program shall include monitoring required for compliance and operations.

7. The Department has designated the WF-21 reclamation project as a groundwater recharge research and demonstration project. Therefore, a plan of study, acceptable to CRWQCB and the Department, to determine the effects of injecting 100 percent reclaimed water and the fate and mechanisms of removal of contaminants of potential health concern, including TOC, shall be developed and implemented. The plan shall be approved prior to initiation and use of 100% reclaimed water. The study shall include the construction of additional monitoring wells at intervals between injection wells and extraction wells. The plan of study shall also address the following issues: characterization of TOC, special water quality monitoring, and tracing movement of reclaimed water. The potential impacts on groundwater quality from using chlorinated deep well water with high organic content (3 to 4 mg/l annual average TOC during the past 5 years) for blending with reclaimed water are not known and shall be evaluated as part of the study.

8. OCWD shall adopt an ordinance or resolution which effectively prevents construction of new public water supply wells for domestic use within 2000 feet of the barrier.

9. OCWD shall monitor domestic water supply wells in the vicinity of the injection barrier and shall immediately provide an alternate safe water supply approved by the Department if a domestic water supply well is no longer usable as a safe, wholesome, and potable source of drinking water as a result of the recharge project.

10. OCWD shall submit an annual report of findings prepared by a qualified engineer regarding the operation of the WF-21 facilities and the Talbert Barrier and the results of the monitoring and investigations of the impacts of the injection operation.

11. The maximum amount of water injected in the Talbert Barrier project shall not exceed 25 MGD, of which the maximum reclaimed water volume shall not exceed 18 MGD based on the average day in any quarter.

9/30/91
Date

Peter A. Rogers, P.E., Chief
Office of Drinking Water
Department of Health Services
Hearing Officer

ORGANIC CHEMICAL ANALYSES

Date of Report:_____ Sample ID No._____

Laboratory Name:_____ Signature Lab Director:_____

Name of Sampler:_____ Employed By:_____

Date/Time Sample Collected:_____ Date/Time Sample Received @ Lab:_____ Date Analyses Completed: _____

==========

System Name:_____ System Number:_____

Name or Number Of Sample Source: _____

User ID: |_|_|_| Station Number: |_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|_|

Date/Time of Sample: |_|_|_|_|_|_|_|_|_|_|_|_| (Y Y M M D D T T T T) Laboratory Code: |_|_|_|_|

Date Analyses Completed: |_|_|_|_|_|_| (Y Y M M D D)

Submitted by: _____ Phone #: _____

REGULATED ORGANIC CHEMICALS

TEST METHOD	CONSTITUENT ALL CONSTITUENTS REPORTED ug/L	ENTRY #	ANALYSES RESULTS	MCL ug/L	* DLR ug/L
	Bromodichloromethane	32101			0.50
	Bromoform	32104			0.50
	Chloroform (Trichloromethane)	32106			0.50
	Dibromochloromethane	32105			0.50
	Total Trihalomethanes (THM'S/TTHM)	82080		100	0.50
	Benzene	34030		1	0.50
	Carbon tetrachloride	32102		.5	0.50
	Ethyl benzene	34371		680	5.0
	1,4-Dichlorobenzene (p-DCB)	34571		5	0.50
	1,1-Dichloroethane (1,1-DCA)	34496		5	0.50
	1,2-Dichloroethane (1,2-DCA)	34531		.5	0.50
	1,1-Dichloroethylene (1,1-DCE)	34501		6	0.50
	cis-1,2-Dichloroethylene	77093		6	0.50
	trans-1,2-Dichloroethylene	34546		10	0.50
	1,2-Dichloropropane	34541		5	0.50
	Total 1,3-Dichloropropene	34561		.5	0.50
	Monochlorobenzene (Chlorobenzene)	34301		30	1.0
	1,1,2,2-Tetrachloroethane	34516		1	0.50
	Tetrachloroethylene (PCE)	34475		5	0.50
	1,1,1-Trichloroethane (1,1,1-TCA)	34506		200	1.0
	1,1,2-Trichloroethane (1,1,2-TCA)	34511		32	1.0
	Trichloroethylene (TCE)	39180		5	0.50

* Detection Limit for Reporting purposes

DHS KEU 001-B QA (4/91)

REGULATED ORGANIC CHEMICALS CONTINUED

TEST METHOD	CONSTITUENT ALL CONSTITUENTS REPORTED ug/L	ENTRY #	ANALYSES RESULTS	MCL ug/L	* DLR ug/L
	Trichlorofluoromethane (Freon 11)	34488		150	1.
	Trichlorotrifluoroethane (Freon 113)	81611		1200	10.
	Vinyl chloride (VC)	39175		.5	0.50
	m,p-Xylene	A-014			10.
	o-Xylene	77135			10.
	Total Xylenes (m,p & o)	81551		1750	10.
	Dibromochloropropane (DBCP)	38761		.2	0.01
	Ethylene Dibromide (EDB)	77651		.02	0.02
	Endrin	39390		.2	0.1
	Lindane (gamma-BHC)	39340		4	0.2
	Methoxychlor	39480		100	10.
	Toxaphene	39400		5	1.0
	Chlordane	39350		.1	0.10
	Diethylhexylphthalate (DEHP)	39100		4	3.0
	Heptachlor	39410		.01	0.01
	Heptachlor epoxide	39420		.01	0.01
	Atrazine (AAtrex)	39033		3	1.0
	Molinate (Ordram)	82199		20	2.0
	Simazine (Princep)	39055		10	1.0
	Thiobencarb (Bolero)	A-001		70	1.0
	Bentazon (Basagran)	38710		18	2.0
	2,4-D	39730		100	10.
	2,4,5-TP (Silvex)	39045		10	1.0
	Carbofuran (Furadan)	81405		18	5.0
	Glyphosate	79743		700	25.0

UNREGULATED ORGANIC CHEMICALS

TEST METHOD	CONSTITUENT ALL CONSTITUENTS REPORTED ug/L	ENTRY #	ANALYSES RESULTS		* DLR ug/L
	Bromobenzene	81555			0.50
	Bromochloromethane	A-012			0.50
	Bromomethane (Methyl Bromide)	34413			0.50
	n-Butylbenzene	A-010			0.50
	sec-Butylbenzene	77350			0.50
	tert-Butylbenzene	77353			0.50
	Chloroethane	34311			0.50
	2-Chloroethylvinyl ether	34576			1.0
	Chloromethane (Methyl Chloride)	34418			0.50
	2-Chlorotoluene	A-008			0.50
	4-Chlorotoluene	A-009			0.50
	Dibromomethane	77596			0.50
	1,2-Dichlorobenzene (o-DCB)	34536			0.50
	1,3-Dichlorobenzene (m-DCB)	34566			0.50
	Dichlorodifluoromethane	34668			1.0
	1,3-Dichloropropane	77173			0.50
	2,2-Dichloropropane	77170			0.50
	1,1-Dichloropropene	77168			0.50
	Hexachlorobutadiene	34391			0.50
	Isopropylbenzene (Cumene)	77223			0.50
	p-Isopropyltoluene	A-011			0.50
	Methylene chloride	34423			1.0

TEST METHOD	CONSTITUENT ALL CONSTITUENTS REPORTED ug/L	ENTRY #	ANALYSES RESULTS		* DLR ug/L
	Naphthalene	34696			0.50
	n-Propylbenzene	77224			0.50
	Styrene	77128			0.50
	1,1,1,2-Tetrachloroethane	77562			0.50
	Toluene	34010			10.0
	1,2,3-Trichlorobenzene	77613			0.50
	1,2,4-Trichlorobenzene	34551			0.50
	1,2,3-Trichloropropane	77443			0.50
	1,2,4-Trimethylbenzene	77222			0.50
	1,3,5-Trimethylbenzene	77226			0.50
	Methyl ethyl ketone (MEK, Butanone)	81595			5.0
	Methyl isobutyl ketone (MIBK)	81596			5.0
	bis (2-Chloroethyl) Ether	34273			5.0
	Alachlor (Alanex)	77825			1.0
	Bromacil (Hyvar)	82198			10.
	Diazinon	39570			0.02
	Prometryn (Caparol)	39057			2.0
	Chlorothalonil (Daconil, Bravo)	70314			5.0
	Dimethoate (Cygon)	38458			10.
	Aldicarb (Temik)	39053			3.0
	Diuron	39650			1.0

Laboratory comments and description of any additional compounds found:

Metals

Antimony
Arsenic
Beryllium
Cadmium
Chromium
Copper
Lead
Mercury
Nickel
Selenium
Silver
Thallium
Zinc

Miscellaneous

Cyanide
Asbestos*

*Not required unless specifically requested.

Pesticides

Method 608

Aldrin
Chlordane
Dieldrin
4, 4' - DDT
4, 4' - DDE
4, 4' - DDD
Alpha Endosulfan
Beta Endosulfan
Endosulfan Sulfate
Endrin
Endrin Aldehyde
Heptachlor
Heptachlor Epoxide
Alpha BHC
Beta BHC
Gamma BHC
Delta BHC
Toxaphene
PCB 1016
PCB 1221
PCB 1232
PCB 1242
PCB 1248
PCB 1254
PCB 1260

Base/Neutral Extractibles

Method 625

Acenaphthene
Benzidine
1, 2, 4 - Trichlorobenzene
Hexachlorobenzene
Hexachloroethane
Bis (2-Chloroethyl) Ether
2 - Chloronaphthalene
1, 2 - Dichlorobenzene
1, 3 - Dichlorobenzene
1, 4 - Dichlorobenzene
3, 3'- Dichlorobenzidine
2, 4 - Dinitrotoluene
2, 6 - Dinitrotoluene
1, 2 - Diphenylhydrazine
Fluoranthene
4 - Chlorophenyl Phenyl Ether
4 - Bromophenyl Phenyl Ether
Bis (2 - Chloroisopropyl) Ether
Bis (2 - Chloroethoxy) Methane
Hexachlorobutadiene
Hexachlorocyclopentadiene
Isophorone
Naphthalene
Nitrobenzene
N - Nitrosodimethylamine
N - Nitrosodi - N - Propylamine
N - Nitrosodiphenylamine
Bis (2 - Ethylhexyl) Phthalate
Butyl Benzyl Phthalate
Di - N - Butyl Phthalate
Di - N - Octyl Phthalate
Diethyl Phthalate
Dimethyl Phthalate
Benzo (A) Anthracene
Benzo (A) Pyrene
Benzo (B) Fluoranthene
Benzo (K) Fluoranthene
Chrysene
Acenaphthylene
Anthracene
1, 12 - Benzoperylene
Fluorene
Phenanthrene
1, 2, 5, 6 - Dibenzanthracene
Indeno (1, 2, 3 - CD) Pyrene
Pyrene
TCDD

Acid Extractibles

Method 625

2, 4, 6 - Trichlorophenol
P - Chloro - M - Cresol
2 - Chlorophenol
2, 4 - Dichlorophenol
2, 4 - Dimethylphenol
2 - Nitrophenol
4 - Nitrophenol
2, 4 - Dinitrophenol
4, 6 - Dinitro - O - Cresol
Pentachlorophenol
Phenol

Volatile Organics

Method 601/602

Acrolein
Acrylonitrile
Benzene
Carbon Tetrachloride
Chlorobenzene
1, 2 - Dichloroethane
1, 1, 1 - Trichloroethane
1, 1 - Dichloroethane
1, 1, 2 - Trichloroethane
1, 1, 2, 2 - Tetrachloroethane
Chloroethane
Chloroform
1, 1 - Dichloroethylene
1, 2 - Trans Dichloroethylene
1, 2 - Dichloropropane
1, 2 - Dichloropropylene
Ethylbenzene
Methylene Chloride
Methyl Chloride
Methyl Bromide
Bromoform
Bromodichloromethane
Trichlorofluoromethane
Dichlorodifluoromethane
Dibromochloromethane
Tetrachloroethylene
Toluene
Trichloroethylene
Vinyl Chloride
Bis (chloromethyl) Ether
2 - Chloroethyl Vinyl Ether

SAN DIEGO PROJECTS

Ken Thompson
Irvine Ranch Water District

1:35 pm -- 2:10 pm

CITY OF SAN DIEGO
POTABLE REUSE OF RECLAIMED WATER: FINAL RESULTS

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Abstract

Water reclamation is becoming a common component of water resource planning. In the past, the driving motivation for water reuse was to provide a means of avoiding effluent disposal into surface waters. With continued drought and increased water demand, reclaimed wastewater is now considered an important water resource. Non-potable and potable use of reclaimed water can enable communities to maximize and extend the use of limited water resources.

This paper summarizes results from the Health Effects Study (HES) portion of the City of San Diego's Total Resource Recovery Project, which includes study and implementation of an advanced wastewater treatment system. The HES represents the product of a substantial research effort to estimate the potential health risk associated with the reclaimed water relative to an existing raw water supply to the City.

HEALTH EFFECTS STUDY (HES)

HES Objectives

The primary objective of the HES was to investigate if the City's advanced wastewater treatment system could reliably reduce the contaminants of concern to levels such that the health risks posed by the treated water to the population are no greater than those associated with the present

water supply. The HES was designed to determine possible health risks of direct reuse of reclaimed wastewater[1].

Public health jurisdictions have not accepted such direct reuse because of concerns that the "raw" water supply, sewage in this instance, can be expected to contain infectious and toxic materials; because of the uncertainty as to the quality requirements for a safe drinking water regardless of the source; and because public health authorities have worked for decades to provide "pure and safe" drinking water and the deliberate reuse of wastewater runs counter to traditional patterns of water use.

HES Organization

The Western Consortium for Public Health entered into a contract with the City of San Diego in July of 1985 to conduct a Health Effects Study (HES) for the City of San Diego. In order to provide overall guidance on the project to the City, the City of San Diego formed a Technical Advisory Committee (TAC) and a Health Advisory Committee (HAC) made up of representatives from the California Department of Health Services, the University of California at Berkeley, San Francisco, Davis, and Los Angeles, the San Diego Health Department, and the California Water Resources Control Board. The HAC provided guidance and review on the technical aspects of the project and is completing the final assessment of the health risks associated with the use of treated wastewater as a potable water supply.

The technical work was carried out by staff of the Western Consortium and a group of subcontractors that included professors and staff from the California universities noted above, San Diego State University, and the virus and microbial laboratories of the California Department of Health Services.

WASTEWATER TREATMENT SYSTEM (AQUA II)

The wastewater treatment system that was studied in San Diego (Aqua II, located in Mission Valley) is a unique and innovative system, utilizing channels containing water hyacinths for secondary treatment, followed by an advanced wastewater treatment (AWT) system designed to upgrade the secondary effluent water to a quality equivalent to raw water for potable reuse. The Water Hyacinth System, when operated within appropriate loading parameters, has produced secondary effluent Biological Oxygen Demand (BOD) and Total Suspended Solids (TSS) concentrations consistently below 10 mg/l. This effluent serves as the feed water to the

Advanced Wastewater Treatment Plant. A more detailed discussion of the evolution of aquatic portion of the wastewater treatment pilot plant is contained in a paper by Tchobanoglous[2].

The AWT plant contains a full range of advanced wastewater and water treatment unit processes, including coagulation, filtration, reverse osmosis, air stripping, carbon absorption, and final disinfection. The effluent from the advanced wastewater treatment represents a potential raw water supply for the City of San Diego which has been investigated in the study herein described, and has been compared to the City's present raw water supply.

HEALTH EFFECT STUDY ELEMENTS

The study included elements for identifying, characterizing, and quantifying infectious disease agents and potentially-toxic chemicals, and for screening mutagenicity and bioaccumulation of the chemical mixtures present, in both the treated wastewater and the City's untreated potable water supply. The untreated water supply was represented by raw water entering the Miramar Water Treatment Plant. The study also included a reliability analysis, using data from the technical performance evaluation of unit processes in the demonstration water reclamation plant. Also, the evaluation included conducting an epidemiology study to collect baseline data of the San Diego population and conducting a chemical risk assessment on both waters. A summary of the results from each of the study elements is presented below.

Infectious Disease Agents

Data sufficient to make an informed judgment as to the public health risk of infectious disease from agents in both the reclaimed water and the untreated raw water supply were collected. The infectious agents that were measured included representative bacterial, viral, and parasitic human pathogens.

The data collected over a two and one-half year monitoring program indicates the following:

- During the monitoring period, 53,576 gallons of Aqua II effluent and 43,028 gallons of Miramar water were concentrated for viruses. No in situ viruses were detected, in samples as large as 1,000 gallons (3800L), in either Aqua II product water or the Miramar raw water, indicating there is no difference in the virus concentration found in the two waters.

- As shown in Table 1, the AWT product water has a much higher microbiological quality than Miramar water based on indicator organism data (i.e. total and fecal coliform and enterococcus).

- The microbiology of the AWT water, without disinfection, meets all microbiological criteria for recreational waters (fresh and marine) and raw drinking water source requirements.

- No enteric bacterial pathogens (i.e. *Salmonella, Shigella,* and *Campylobacter*) were detected in either the Aqua II or the Miramar waters.

Table 1
Summary Statistics for Indicators in All Waters*
(MPN/100mL)

Indicator	Water Source	Sample Size	Log Avg.	Log S.D.	Min.	Max.
Total Coliform	RWW	212	7.37	0.31	6.11	8.20
	MIRAMAR	428	1.51	0.82	0.30	3.70
	AWT	413	0.40	0.28	0.30	1.90
Fecal Coliform	RWW	212	7.05	0.32	6.32	8.20
	MIRAMAR	425	0.50	0.36	0.30	2.48
	AWT**	413	0.30	0.00	0.30	0.30
Enterococcus	RWW	196	6.48	0.34	5.60	7.38
	MIRAMAR	425	0.95	0.77	0.00	3.20
	AWT	411	0.30	0.00	0.30	0.30

* Does not include duplicates.
** For statistical purposes values of less than 2.2 MPN/100 ml were recorded as 2.2 MPN/100 ml. The majority of the samples were <2.2 MPN/ml.

Chemical Agents

Chemical screening and monitoring of the Aqua II and Miramar waters was carried out over a three year period. The objectives of this element were twofold; one, determine which chemicals are present and their concentrations; and two, identify which of these chemicals are known to be of concern to human health if the AWT water were used as a municipal raw water source. What follows is a brief summary of the work[3].

Results of Chemical Analysis: Miramar and AWT waters were analyzed for inorganics, purgeable organics, extractable organics, pesticides, Polychlorinated Biphenyls (PCBs), and chlorinated dibenzodioxins/dibenzofurans. Most contaminant levels in the reclaimed water were extremely low; well below conventional detection limits. Results of the Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) analysis indicated that boron, calcium, magnesium, manganese, molybdenum, phosphorus, sodium and strontium occurred in measurable quantities in both Miramar and AWT waters. Arsenic was identified in the Miramar water by Atomic Absorption Spectroscopy (AA) analysis at very low concentrations, mean value of 1.5 ug/l and not detected in the Aqua II water.

Results of the purgeable organic analyses indicated that analytes measured above detection limits in AWT water were also found in a few blanks and sometimes in Miramar water. Trihalomethanes (THMs) were among the compounds detected in the Miramar water at concentrations averaging 10 ug/l; byproducts of upstream chlorination in route from Lake Skinner. Tests conducted to identify the THM formation potential in both waters indicated that the Miramar water was ten times that of the AWT water.

The only extractable organic compounds measured above detection limits in either AWT or Miramar water were phthalates: Bis(2-ethylhexyl)phthalate, diethyl phthalate and di-n-octyl phthalate. BEHP essentially represents the only significant compound of public health concern and was identified at values in the AWT water ranging from <0.5 ug/l geometric mean to 7.6 ug/l arithmetic mean and in Miramar from <0.5 ug/l geometric mean to 4.2 ug/l arithmetic mean. No PCBs, pesticides or dioxin/furans were identified above detection limits in either AWT or Miramar waters.

The average total organic carbon (TOC) concentration found in Aqua II water was 1.37 ug/l; while TOC concentration averaged 9.83 ug/l in Miramar water.

Results of Genetic Toxicity Testing: Genetic toxicity testing was used as a relatively cost effective bioassay for screening the relative toxicity of the two waters being investigated. Four separate types of widely used bioassay systems were employed to assess genetic toxicity and potential cancer-causing effects of the AWT and the Miramar waters. These included the Ames Assay, Micronucleus Test, 6-Thioguanine Resistance Assay, and Cellular Transformation Assay.

Mutagenic and genotoxic activity has been frequently observed in studies of source and treated waters. Consistent with these observations, organic extracts from both the AWT and the

Miramar water sources exhibit some mutagenic activity. In addition, some genotoxic activity may also be associated with fractions which were not efficiently extracted by the resin columns used in these studies. The genotoxic effects detected in this study were observed primarily in the Ames test but some indications of potential mutagenic activity were also observed in the other bioassays. Based on the Ames test data, the tested Miramar extracts exhibited somewhat higher mutagenic activity than the comparable AWT extracts. The reason for this difference in observed mutagenicity is unknown, but may reflect differences in composition of the original source waters or the result of the use of disinfectants on Miramar water.

These data from short-term bioassay results of organic extracts of both AWT and Miramar water indicate that water from the AWT facility appears to exhibit less genotoxic or mutagenic activity than the low levels observed in water from the raw water entering the Miramar Water Treatment Plant.

GCMS Identification of Chemical Substances: Synthetic resins were used to concentrate trace organics from AWT, Miramar and reagent (blank) water. A total of 71 resin extracts were analyzed by gas chromatography/mass spectrometry in an effort to characterize the component mixture. The resin extract for each sample was fractionated by High Performance Liquid Chromatography (HPLC) into four fractions with one of the fractions fractionated again into three subfractions resulting in a total of six fractions for each sample. Analysis of resin accumulated organic residues from AWT and Miramar waters revealed the presence of many classes of organic compounds in low to trace amounts in the waters. Several herbicides were found in four of the five Miramar water samples. Only one compound found in the monthly water samples, 2-hexenal, was predicted to be an active mutagen and reported positive in the *Salmonella* testing.

Fish Biomonitoring

To complement information from other HES activities, the fish biomonitoring experiments were expected to provide information on chronic exposure to trace contaminants contained in the effluent from the Aqua II Plant and the untreated raw City water that accumulate in tissue but are not known to be in genetic toxicity screening bioassays[4].

Juvenile fathead minnows (*Pimephales promelas*) were exposed to Aqua II water, Miramar water, or charcoal filtered San Diego tap water (acclimation or control water) in flow-through aquaria. Three 28-day bioaccumulation experiments were completed at each site under

standardized conditions following EPA and ASTM bioconcentration guidelines. In addition, swim speed and optomotor response tests were conducted.

A total of 120 fish tissue samples and 60 aquarium water samples were collected for analysis of 69 base/neutral/acid extractable organics, 27 pesticides/PCBs, and 26 inorganics by investigators at the University of California at Los Angeles (UCLA). Quadruplicate samples of fish tissue and either duplicate or triplicate samples of water were collected and analyzed for each sampling time (Days 0, 7, 14 and 28 of the 28-day experiments). The concentrations of most analytes in these samples were either zero or below the detection limit. Statistical comparisons were made only if at least 75% of the samples exceeded the detection limit for a given analyte. Chemical analysis of fish tissue and water in the 28-day bioconcentration experiments revealed no statistically significant differences.

The fish displayed no significant difference in survival, growth, or swim speed after up to 28 days of continuous whole body exposure to either Aqua II or Miramar water under test conditions. This was a consistent finding for all three tests conducted on each of the three waters.

Plant Reliability

Evaluating the risk associated with the AWT plant effluent includes considering the ability of the treatment system to consistently achieve the level of treatment that was used as the basis for the health risk assessment. Therefore, the overall reliability of the San Diego Aqua II Pilot Plant was evaluated.

The objectives of the reliability analysis were to determine the reliability of the mechanical systems, characterize the treatment process variability, and present the probabilities of effluent characteristics meeting specific observed concentrations. To address these objectives, the reliability analysis included the review and analysis of plant performance and mechanical systems data.

Summary statistics of the water quality data showed very effective treatment, with virtually complete removal of biological indicator organisms, and removals on the order of 87% to 98% for general parameters, "conventional" pollutants, and for most inorganic ions. The treatment plant was slightly less effective at removing metal ions, with observed removals on the order of 74% to 91%.

In evaluating the inherent reliability of the AWT plant, an effort was made to identify comparable facilities and compare the effectiveness and variability of treatment at those similar facilities. Denver Potable Water Reuse Project, the Water Factory 21 Advanced Wastewater Reclamation Project, and the Potomac Estuary Experimental Water Treatment Plant were evaluated for this purpose.

The observed treatment effectiveness at Aqua II appeared to be consistent with the experience at other similar facilities, although the effectiveness of metals removal may have been somewhat less than that which was observed at Water Factory 21.

The levels of treatment obtained at the Aqua II Plant were sufficient to meet all existing drinking water standards for all of the data reviewed in this study. The results of the statistical analysis and the mechanical reliability analysis indicate that compliance with Maximum Contaminant Levels (MCLs) can be maintained at the Aqua II demonstration AWT plant, on a long-term basis, with low probability of exceeding MCL concentrations (generally less than 1 in 1,000 for individual metals).

Results of the mechanical reliability analysis indicate that, over a two and one-half year period, the critical equipment is operational nearly 100% of the time. In addition, the mechanical reliability analysis confirms statistically what is known practically about the Aqua II Plant: observed equipment failures do not cause a significant interruption in operation of the plant.

Seeding Studies

Chemical and virus seeding studies were conducted at the Aqua II Plant. The results of that work are described below:

- Chemical Seeding Study: The Aqua II Plant was spiked with both organic and inorganic constituents that could potentially enter a wastewater treatment plant as a large pulse flow. A summary of the results of this work is shown in Table 2. As shown, the ponds removed 60–99% of the inorganic and organic seed, and the advanced treatment processes removed >98.5 – >99.9% of the seed. Overall, the Aqua II Plant removed >99.5 – >99.997% of the seeded chemical constituents[3].

Table 2
Chemical Removal Efficiency by
Hyacinth Ponds and the AWT Facility - Spike Study

Compound	Spike (ug/l)	Pond Effluent (ug/l)	% Removal by pond	AWT Effluent (ug/l)	% Removal by AWT	Overall
Chromium	182	74	59.3	<1.00	>98.6	>99.500
Tetrachloroethylene	900	29	96.8	<0.03	>99.9	>99.997
Tetrachloroethane	224	53	76.3	<0.10	>99.8	>99.996
Trichlorobenzene	813	130	84.0	<0.30	>99.8	>99.996
Tetrachlorobenzene	140	2	98.6	<0.03	>98.5	>99.980
Lindane	70	12	82.9	<0.03	>99.7	>99.960

- Virus Seeding Study: Four virus seeding studies performed on the Aqua II Plant indicated a very high virus removal capability. None of the seeded virus (attenuated vaccine strain Poliovirus 2) were recovered in the final effluent indicating a removal efficiency of as great as eight orders of magnitude (99.999999%). This removal rate is considerably greater than that reported in either the Pomona virus study[5] or the Monterey study[6] which used filtration and chlorination of secondary effluent but not reverse osmosis without final disinfection.

Epidemiology

The principal purpose of the epidemiology component was to develop a baseline of pertinent morbidity and mortality data for the City of San Diego so that a basis of comparison is available if recycling of municipal wastewater becomes a reality. Three different methods for epidemiological monitoring were evaluated for possible utilization should total resource recovery be adopted operationally by the City of San Diego.

The health of the residents was evaluated by characterizing the reproductive health and analyzing vital statistics of San Diego County. In addition, a neural tube defects survey was performed to establish baseline prevalence rates in California and in San Diego.

The epidemiological component provided baseline data to facilitate monitoring for actual health effects if the City decides to proceed with potable reuse of the type of treated effluent studied in this project[7].

Chemical Risk Assessment

The chemical risk estimates were driven by Arsenic and THMs present in the Miramar water (THMs apparently from upstream chlorination of the raw water supply), and by bis-ethyl hexyl phthalate (BEHP) present in the Aqua II water. Arsenic accounts for approximately 80% of the risk estimate in Miramar water, and THMs account for approximately 20% of the estimate in Miramar water. The concentration of arsenic in Miramar water is well within applicable Federal and State standards, approximately 2% of the existing drinking water standards. The concentration of THMs in the Miramar water is 10% of the existing drinking water standards. The water from the Aqua II system was analyzed for arsenic and does not have enough arsenic to be reliably detected.

Risk calculations, using EPA upper confidence level estimates, indicate that the Aqua II water, if used directly as potable water, would represent an estimated lifetime risk of 3.2×10^6 (0.03 excess cancers/10,000 people) versus 1.2×10^4 (1.2 excess cancers/10,000 people) for Miramar water. These estimates indicate that the Aqua II risk estimate is approximately 40 times less than the estimated risk associated with the untreated Miramar water.

Results of the non-carcinogenic risk indicated that, for both waters, non-carcinogenic chemicals at observed low concentrations would not be anticipated to result in any significant health risk.

CONCLUSION

Based on the above research, the overall conclusion reached by the Health Advisory Committee was that the health risk associated with the use of the Aqua II (AWT water) as a raw water supply is less than or equal to that of the use of the existing raw water supply as represented by Miramar.

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CHEMICAL and BIOLOGICAL PROCESSES in the VADOSE ZONE

Field Studies
Gray Wilson
University of Arizona

Laboratory Studies
Bob Arnold
University of Arizona

2:10 pm -- 3:00 pm

THE ROLE OF SOIL AQUIFER TREATMENT (SAT) IN WASTEWATER RECLAMATION/REUSE; HYDROLOGICAL, CHEMICAL, AND MICROBIOLOGICAL CONSIDERATIONS

TECHNICAL SUMMARY

PREPARED FOR TUCSON WATER AND THE SALT RIVER PROJECT

PART 1
FATE OF CHLORINATION BYPRODUCTS DURING SAT

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Revised March 19, 1992

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THE ROLE OF SOIL AQUIFER TREATMENT (SAT) IN WASTEWATER RECLAMATION/REUSE; HYDROLOGICAL, CHEMICAL, AND MICROBIOLOGICAL CONSIDERATIONS

INTRODUCTION

Several years ago, Tucson Water incorporated golf course irrigation into their overall water conservation program. This involved constructing a tertiary water-treatment plant (called the Roger Road Reclaimed Water Treatment Plant) and pipeline network for delivering tertiary effluent to golf courses for turf grass irrigation. With this system in place, the demand for ground water as an irrigation source has been reduced. An operational problem with this approach is that water generated by the plant must be stored during non-peak demand periods (Fall through Spring) for recovery in the Summer, when the demand is high. Tucson Water solved this problem by storing off-season surpluses underground for recovery later during peaking periods. A phased approach was used in designing the system. In 1986, the City of Tucson began a demonstration project, recharging tertiary effluent from the Roger Road Reclaimed Water Treatment Plant in four spreading basins. This study showed that subsurface storage and recovery is feasible. In 1990 the project was enlarged from 3 to 14 wetted acres, and named the Sweetwater Underground Storage and Recovery Facility (see Figure 1). Recharged water is recovered using three extraction wells. Based on projected demand estimates for tertiary effluent, about 6,500 acre feet will be annually recharged by 1998.

Recharging wastewater by spreading in basins offers another advantage besides storage: additional treatment. Such treatment is known as soil aquifer treatment (SAT). (A glossary of terms is included herein as an attachment.) In California, this process is also known as Rapid Infiltration and Recovery (RIX). The basic approach in SAT is to apply sewage effluent at a high rate to soils within a water-spreading area, promoting renovation of the effluent as it flows through the vadose zone and water-bearing formations. The pioneering studies on SAT were conducted in Phoenix, Arizona, by the U.S. Water Conservation Laboratory (Bouwer, 1985). These studies showed that SAT typically removes suspended solids and pathogenic organisms from the water and reduces concentrations of phosphate. Concentrations of heavy metals and other minor elements were also appreciably reduced. At the Phoenix site, it was also found that renovated sewage effluent from SAT systems met the public health, agronomic, and aesthetic requirements for unrestricted irrigation. Thus, from an operational perspective, applying secondary effluent to SAT systems may offset the need to expand existing tertiary treatment plants.

It is also possible that, with suitable pre- and post-treatment, recovered water could be reused for potable purposes. There are three principal concerns when considering SAT in a potable reuse scheme. First, secondary and tertiary treatment does not remove all of the dissolved organic matter in effluent. Dissolved organic

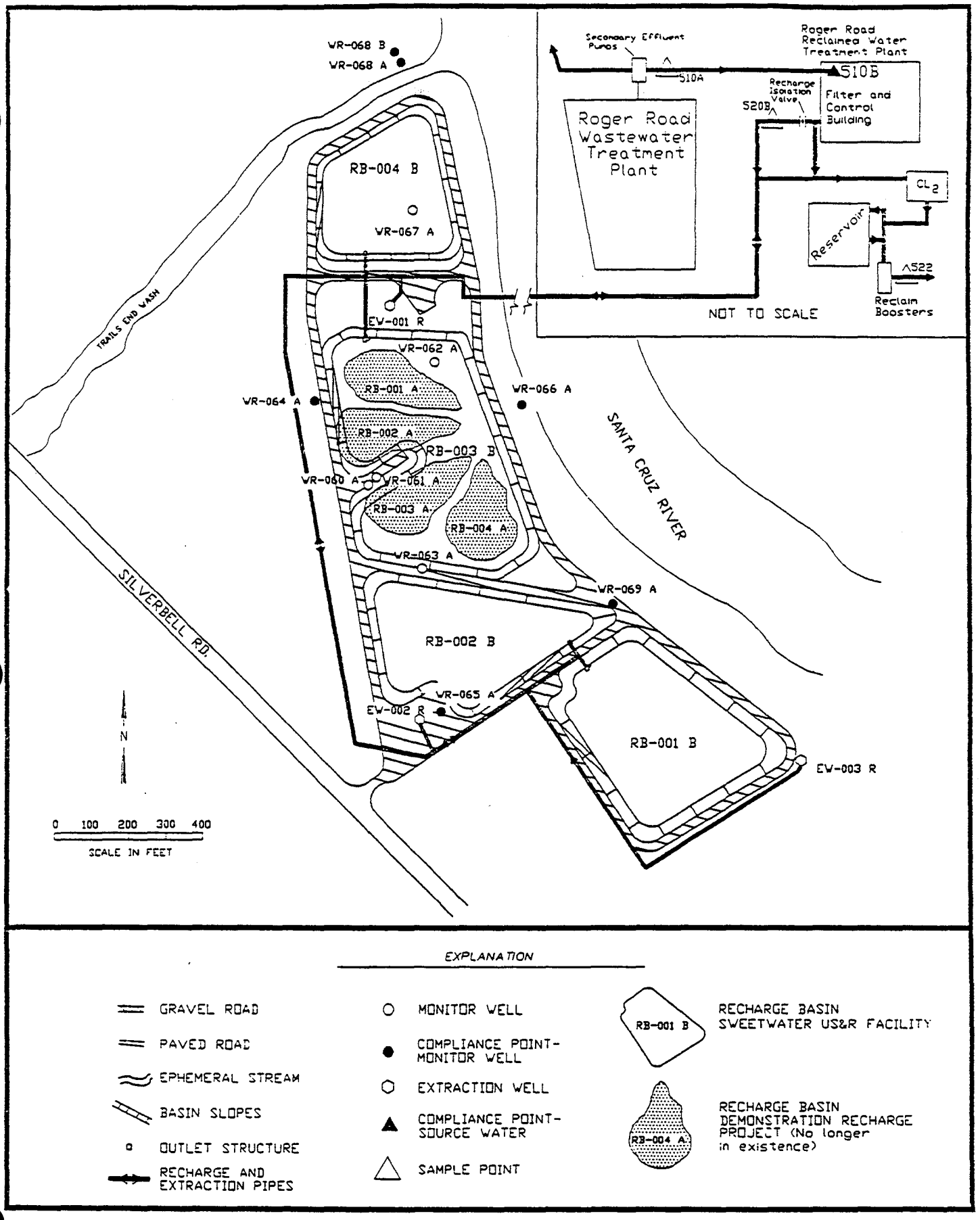


Figure 1. Sweetwater US&R Facility.

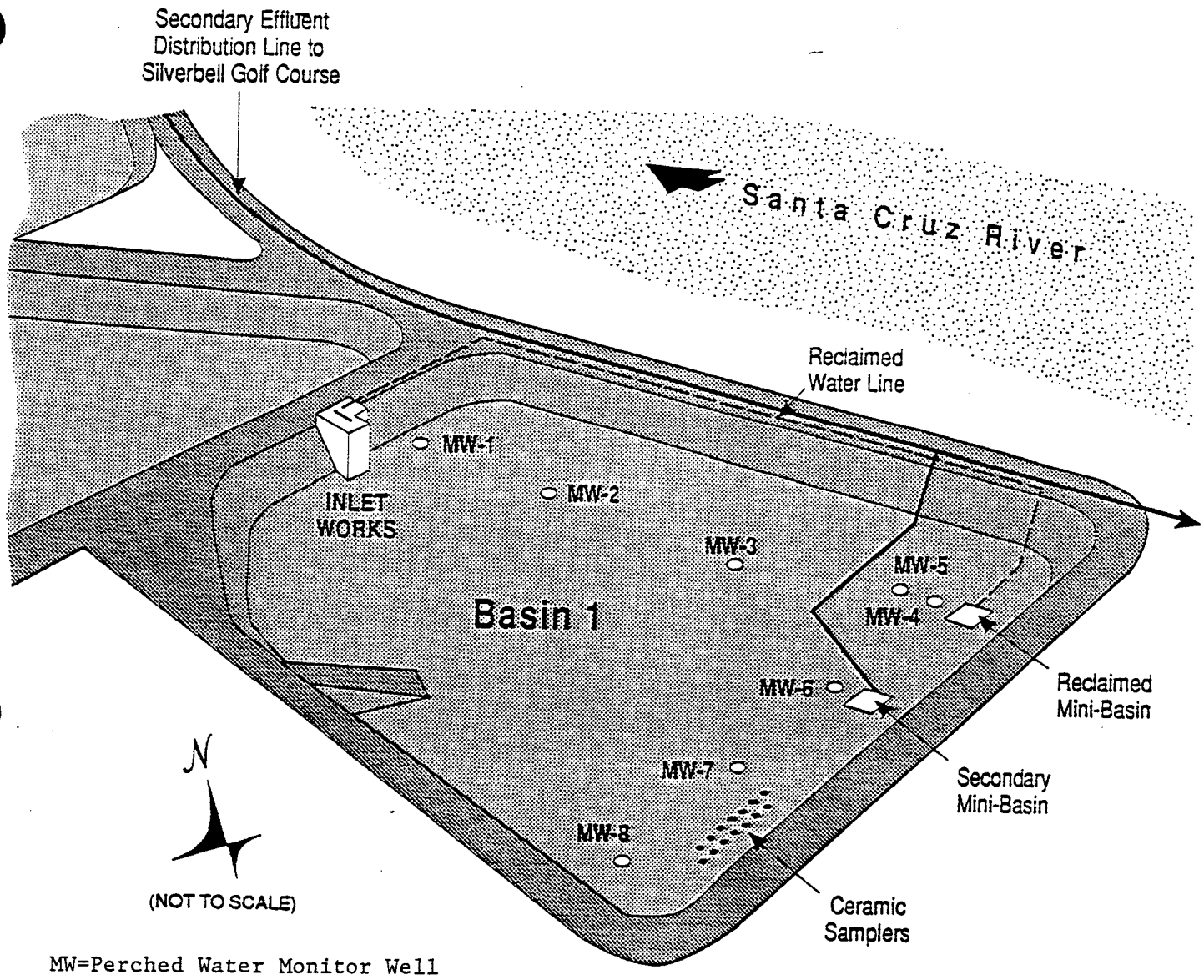
matter is expressed as dissolved organic carbon (DOC). The DOC content of raw effluent is normally about 100 parts per million (i.e., milligrams per liter). The DOC of secondary and tertiary effluent is commonly about 10 parts per million. In contrast, the DOC of Tucson's ground water is about 0.5. DOC is of concern because it contains substances that form disinfection byproducts (DBPs) following chlorination. Trihalomethanes (THMs) are a common DBP of major concern to water utilities because they have been found to be carcinogenic. Currently, the drinking water standard for THMs is 100 parts per billion. However, EPA is considering lowering the standard to between 25 and 50 parts per billion.

Second, the fate of nitrogen species in effluent during SAT is also of concern. For example, nitrogen in the nitrate form has been linked to "blue-baby syndrome". SAT studies in Phoenix demonstrated that nitrate is produced from effluent during recharge. The drinking-water standard for nitrate is 45 parts per million. Third, recovered effluent may contain pathogenic microorganisms. Thus, assessment of treatment options following SAT will need to consider the presence of trace organics, nitrate, and microorganisms in the recovered water.

This report reviews the results of controlled field studies to determine the treatment effectiveness of SAT for both potable and non-potable reuse in Arizona. These studies were conducted in two small test basins (mini-basins) constructed within Basin 1 (see Figure 2) at Tucson Water's Sweetwater Underground Storage and Recovery Facility. The fine-grained overburden at this site was removed to expose coarse-grained sediments favoring rapid infiltration. Thus, results represent "worst-case" conditions. The general goals of the studies were as follows:

- determine the fate of organic matter and chlorinated organics during passage of secondary and tertiary effluent through a soil profile (SAT system);
- determine the fate of nitrogen compounds in the vadose zone during SAT;
- determine the effectiveness of virus removal during SAT; and
- determine the effect of infiltration rate and profile drainage on SAT effectiveness.

Part 1 reviews the results of studies to determine the fate of organic matter in wastewater. Part 2 reviews the results of studies on virus removal.



MW=Perched Water Monitor Well

Basin 1 Schematic

Note: MW = Perched Water Monitor Well

Figure 2. Basin 1, Showing Location of Mini-Basins and Perched Water Monitor Wells

PART 1. FATE OF CHLORINATION BYPRODUCTS DURING SAT

SECTION 1. BACKGROUND, CHEMISTRY OF ORGANO-CHLORINE COMPOUND FORMATION AND NITROGEN TRANSFORMATIONS

Figure 3 illustrates the formation of DBPs during chlorination of secondary sewage effluent:

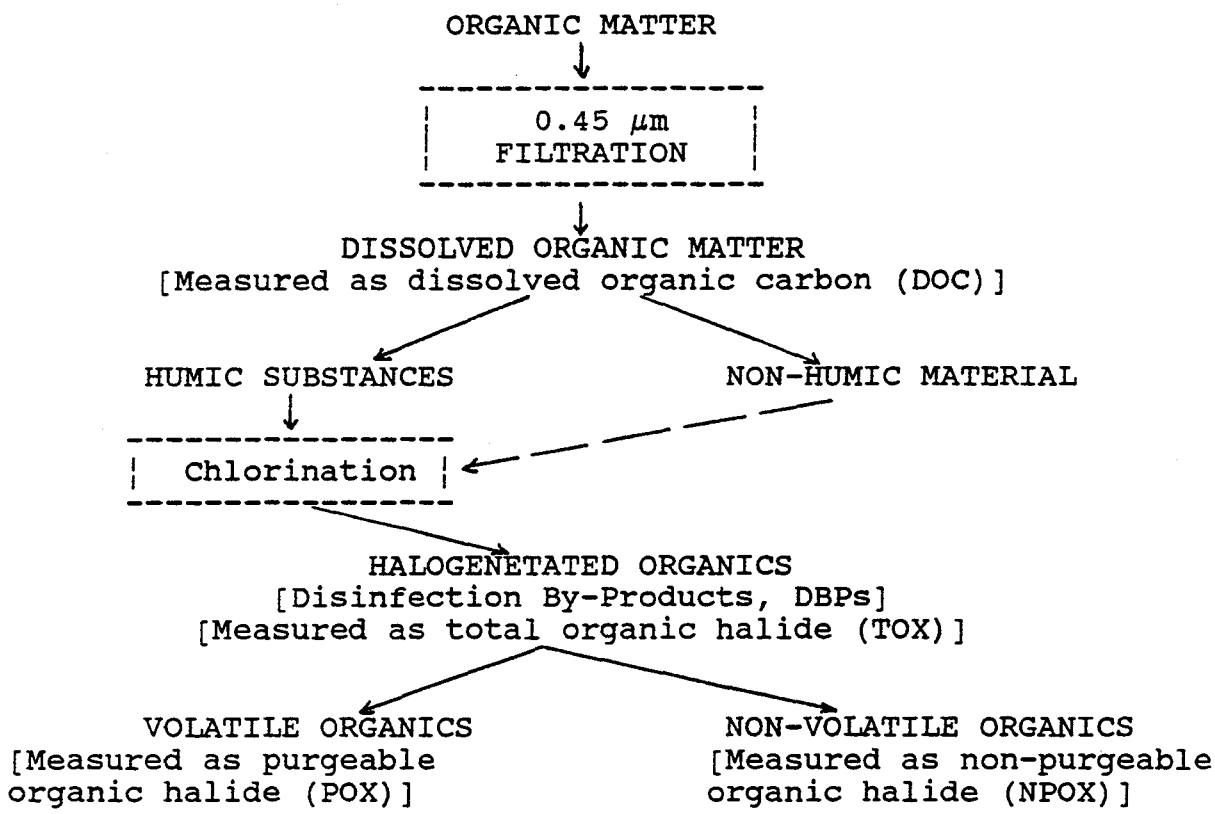


Figure 3
Formation of DBPs

Figure 3 shows that organic matter present in secondary (or tertiary) effluent includes dissolved organic matter, isolated by membrane filtration and measured as DOC. The overall DOC includes humic substances (e.g., humic and fulvic acids) and non-humic material (e.g, carbohydrates, amino acids, and proteins). The humic fraction serves as the actual precursor to the formation of THMs and other DBPs during water treatment. The non humic fraction is less reactive in forming DBPs. THMs typically account for only about 20 percent of the total organic halide (TOX) observed in chlorinated water. The NPOX found in chlorinated drinking water has been shown to be mutagenic.

Little is known about the fate of wastewater-derived TOX in the environment, particularly in the subsurface. In a surface water, POX-related compounds can be expected to volatilize while NPOX material may be affected by photolysis, sorption, biotransformations, and chemical transformations such as hydrolysis. In the subsurface, sorption and biodegradation can be expected to play an important role. However, within the heterogeneous mixture comprising the NPOX, materials will range from more hydrophobic/higher molecular weight chloro-humic acids to more hydrophilic/lower molecular weight chloro-fulvic acids. One would expect the former to be more affected by sorption and the latter to be more mobile in the subsurface. Molecular weight and the structure of chloro-organic compounds also affect biodegradability.

SECTION 2. OBJECTIVES OF FATE STUDIES

General objectives of the field project included:

- o determining the fate of DOC and TOX in a SAT profile;
- o determining the relationship of basin hydraulics (wet-dry cycling, intake rates, water content distribution in the profile) and treatment of secondary and tertiary effluent;
- o contrasting secondary and tertiary effluent as a source water; and
- o determine the relative magnitudes of sorption versus microbiological activity in the fate process.

SECTION 3. FATE STUDY METHODS

3.1 General Overview

The Sweetwater Underground Storage and Recovery Facility is located on the west bank of the Santa Cruz River about one-quarter mile from Pima County's Roger Road Wastewater Treatment Plant. The 14-acre facility consists of four spreading basins, excavated approximately 10 feet below land surface. Excavation removed fine-grained overburden to expose permeable channel alluvium. The channel alluvium, which extends to about 16 feet below the bottom of the basins, consists of large cobbles and gravel intermixed with coarse sand, silt and clay. Underlying the channel alluvium is a basin fill unit comprising finer grained sediments. The water table (1991) is about 120 feet below land surface.

3.2 Water Sources

Water sources available at the site are chlorinated secondary effluent from the Roger Road Wastewater Treatment Plant and tertiary effluent from the Roger Road Reclaimed Water Treatment Plant (Figure 1). The tertiary effluent used in this study was not further chlorinated, although the source water is a chlorinated

secondary effluent. The excavated spreading basins are currently flooded with tertiary effluent, while an adjoining golf course is irrigated with secondary effluent.

3.3 Test Basins

Two steel-walled test basins, each 12 by 12 feet in area, were constructed within Basin 1 (Figure 2). The four-foot-high walls were buried two feet below land surface (bls) allowing two feet of freeboard. One basin was flooded with the secondary supply while the second was flooded with the tertiary water source. Water was metered into each basin. The secondary basin was instrumented with suction lysimeters at the following depths in feet bls: 1.0, 2.5, 5.0, 7.0, 12.5, 14.0, and 20. Depths of similar units in the reclaimed basin were 1.0, 2.5, 5.0, 7.0, 12.5, 12.5, and 20 feet bls. These units permit sampling of percolating pore liquid. Additionally, each basin included a 15-foot access well for neutron moisture logging. Neutron logging data provide a "snapshot" of the moisture conditions in the profile at various times during flooding. During installation of the suction samplers, soil cores were taken to characterize the textural layering and background organic carbon content (f_{oc}). Information on these parameters aided in the interpretation of subsurface flow patterns and quality changes during percolation of effluent.

3.4 Wet-Dry Cycling And Sampling Protocol

Each test basin was flooded during a series of wet-dry cycles. Generally each wetting cycle was seven days in duration followed by seven days of drying. The secondary basin was cycled nine times during the period of July 11 to December 13, 1990. The basin receiving tertiary effluent was cycled seven times during the period of January 10 to April 8, 1991. The access wells were logged with the neutron logger several times during each cycle to determine the change in the relative moisture status of the profiles. Infiltration rates and total inflow volumes were monitored. Samples of the applied water and time-lagged samples of pore water from the lysimeters were collected during five flooding cycles in the secondary basin and during three flooding cycles in the tertiary basin. These samples were analyzed for the organic constituents of interest (DOC and TOX). Surface and subsurface samples were collected during one cycle from both basins for analysis of nitrogen compounds.

SECTION 4. FATE STUDY RESULTS

4.1 Hydraulic Data

The test basins were allowed to drain between cycles. There was no manipulation (e.g., scraping) of the surface during the drying cycles, except for one case (followed by very high infiltration rates).

For a comparable number of flooding cycles (seven) and loading rates, the volume of effluent infiltrated into the secondary basin was about 80 percent of the volume infiltrated into the tertiary basin. The turbidity of the tertiary source averaged about one-third that of the secondary source. Thus, some of the difference may be attributable to greater sediment loading in the secondary source. However, the final infiltration rates were actually slightly lower in the tertiary basin. The observed decline in intake rates between tests in both basins is attributed primarily to the growth of a biofilm on the soil surface which clogs the surface pores. Drying between cycles partially restored the initial infiltration rates.

4.2 Neutron logs

Neutron logging, a geophysical technique, indicates the relative degree of saturation in the profile during flooding and drying. The series of logs obtained in both basins provided the following information:

- the profiles wetted rapidly in the first 24 hours;
- because of textural layering, the greatest changes occurred in the upper four feet and lower five feet with the intermediate zone serving as a transmission region;
- drainage occurred between the 1-day and 7-day profiles, apparently as a result of surface clogging; and
- additional drainage occurred during the drying cycles, reducing water content profiles to preflooded levels.

4.3 Water Quality Data

4.3.1 Organic compounds

Maximum DOC removals of 72 percent and maximum TOX removals of 46 % were achieved with secondary effluent. Slightly higher TOX removals were observed for tertiary effluent. Average DOC and TOX removals were about 50% and 40%, respectively, in secondary effluent. The greatest change occurred near the soil surface, possibly reflecting a buildup of organic carbon in the biofilm layer.

DOC levels decreased with depth and, at a given depth, there was a general decrease in DOC with time. In some but not all cases, there was also a decrease in TOX with depth and time. A possible reason for the observed changes with time is as follows: as infiltration rates decrease and as the water content in the profile decreases (as reflected in the neutron logging data), water percolates at a slower rate, increasing the opportunity for sorption and/or biodegradation of organic compounds.

DOC and TOX mass balances were conducted to define the removal capacity of the soil profile for organic matter, as measured by DOC, and chlorination byproducts as measured by TOX. At this point in our studies, it was not possible to clearly differentiate between the two principal removal mechanisms, sorption and biodegradation.

For secondary effluent, there is some evidence that DOC removal is improved in progressing from initial to subsequent wetting cycles, possibly due to enhanced microbiological transformations. The trend for TOX removal appeared to be somewhat mixed for secondary effluent while a little stronger for tertiary effluent. Recharge with tertiary effluent as a source water appeared to provide slightly better performance in TOX removal than that achieved with secondary effluent.

Throughout the study, the modest levels of instantaneous THMs present in the source waters appeared to be effectively removed by volatilization in ponded water within the basins. (Instantaneous THMs refer to the THM level in water samples at the instant the samples are taken.) The presence of ammonia in the source water lead to little observable reduction of the trihalomethane formation potential (THMFP). [see Singer and Chang (1989) for a review of instantaneous THMs, total THMs, and THMFP.] The reason for this is as follows:

- in source (pond) water samples chlorine that is applied during the THMFP test combines with ammonia to form chloramines, which are less reactive in forming THMs.

Analyses of the apparent molecular weight (AMW) of some of the samples from the vadose zone suggest that higher molecular weight humic material was preferentially removed by the soil mantle over lower molecular weight nonhumic material. This is consistent with the more hydrophobic properties of high molecular weight humic substances. The significant removals of DOC in the soil profile suggests that THM precursors are also reduced. This was not reflected by the results of THMFP tests for the following reason:

- in soil mantle samples (i.e., from the lysimeters), the ammonia present in source water is converted to nitrate (see Section 4.3.2) and applied chlorine is available to form significant THMs, even though DOC levels have been reduced.

4.3.2 Nitrogen compounds

Applied water, suction lysimeter samples, and perched ground-water samples were obtained during one of the later wetting cycles in each basin for analyses of nitrogen compounds. These samples were taken to characterize the changes in nitrogen forms in the profiles during a wetting cycle. Sampling was undertaken during one of the later cycles to ensure that background (i.e., pre-flooding) nitrogen was leached from the profiles. Most of the nitrogen in the source water was in the form of ammonium. Very large values of nitrate (for example, one value was about 770 mg/l) were observed in the first samples taken from the suction lysimeters shortly after the beginning of flooding. This reflects the first flush of nitrate-laden water through the profile. Values peaked in the upper part of the profile. Nitrate levels in samples obtained later in the wetting cycle were markedly reduced below the initially high values.

The trends in nitrate data in both basins are similar to those reported by Bouwer (1985) during rapid infiltration studies at Flushing Meadows, Phoenix, Arizona. He attributed the initial nitrate-nitrogen peaks to the following sequential processes:

- sorption of the ammonium ion (NH_{4+}) onto clays within the soil profile during wetting cycles when air is essentially excluded from the profile;
- microbial conversion of ammonium to nitrate (i.e., nitrification) during drying periods when atmospheric oxygen enters the profile; and
- flushing of a nitrate peak during the next flooding cycle.

The clay content in the upper 3.5 feet averaged 14 percent, compared to lower values at depth. Thus the upper profile appears to serve as a sink for ammonium ions.

Total nitrogen in later samples of perched ground water (about 16 feet bls) beneath the secondary basin was about 70 % of the total applied nitrogen. Factors causing this loss include sorption of ammonia, volatilization, and denitrification.

SECTION 5. FATE STUDY CONCLUSIONS

Table 1 summarizes the fate studies.

5.1 Basin hydraulics

- Intake rates were initially favorable during flooding of the basins but diminished with time between cycles because of surface clogging by particulate matter and a biofilm.

Table 1: Summary of Fate Study

OBJECTIVE	PURPOSE	RESULTS AND CONCLUSIONS
Evaluate the fate of DOC and TOX in a coarse-grained SAT profile.	To determine the percentage removal of source water DOC and TOX during SAT	Both DOC and TOX were reduced during SAT. Average DOC removals of about 50 percent and TOX removals of about 40 percent were achieved with secondary effluent. Slightly higher removals were observed for tertiary effluent. Greater removals are expected for finer-grained profiles.
Evaluate the effect of basin hydraulics on treatment.	To determine the effect of infiltration rates and profile drainage on treatment effectiveness	Treatment appears to increase within and between cycles. Most DOC and TOX removal occurred within the top few feet corresponding to highest organic carbon content. Slower infiltration rates and profile drainage enhance treatment, possibly because of a greater opportunity for biodegradation of humic substances.
Evaluate the fate of nitrogen compounds during SAT.	To determine the distribution of nitrogen compounds in a SAT profile during flooding	The nitrate content of percolating water was high during the beginning of sampling trials in each basin. This appears to reflect nitrification of ammonium adsorbed in the profile during previous flooding cycles.
Contrast treatment using secondary and tertiary sources.	To determine if SAT is an alternative to tertiary treatment and to determine if post treatment is required to bring recovered water to potable standards	SAT provides treatment comparable to Tucson Water's tertiary plant; post-recovery treatment for further reduction of DBP precursors and nitrogen may be required for potable reuse.

- The 20-foot profile monitored during the tests filled rapidly with water; drainage occurred in the profile during the tests because of surface clogging.

5.2 Organic compounds

- Maximum DOC removals of 72 percent and maximum TOX removals of 46 percent were achieved with secondary effluent; slightly higher TOX removals were observed for tertiary effluent.

- Most of the DOC and TOX removal occurred within the top few feet corresponding to a region of higher organic carbon.

- Within a given cycle, improved DOC removal with time was observed, while there was a similar (but weaker) trend for TOX, with some evidence of TOX desorption.

- Over multiple cycles, there was some evidence of improved DOC removal but no clear trend for TOX.

- Removals for tertiary effluent were found to be slightly better than those of secondary effluent.

- There is some evidence that higher molecular weight and humic DOC may be preferentially removed.

- Only modest THMFP reductions were achieved, a result attributable to greater levels of ammonia, and its associated chlorine demand, in source water compared to infiltrated water.

5.3 Nitrogen compounds

High nitrate concentrations, observed in the first flush of water percolating through the profile following drying cycles, may be attributable to the following processes:

- sorption of ammonium-nitrogen on clays during flooding; and

- formation of nitrate-nitrogen in the drying period between wetting cycles.

SECTION 6 IMPLICATIONS FOR MANAGEMENT

Table 2 summarizes the relative treatment effectiveness of SAT and tertiary treatment of secondary effluent.

6.1 Turbidity

Table 2 shows that SAT of secondary effluent provides a level of filtration effectiveness comparable to that in Tucson Water's

Table 2. Comparison of Treatment Processes

PARAMETER	UNITS	SECONDARY EFFLUENT	TERTIARY EFFLUENT	SAT	GROUND WATER
DOC	mg/l	12 to 13	12 to 13	7	1[1]
THM	µg/l	20	17	<5	2[1]
THMFP	µg/l	150 to 190	190 to 200	140 to 150	13[1]
TOX	µg/l	109	92	70	9[1]
AMMONIA-NITROGEN	mg/l	14	7	<1.0	0.4[2]
NITRITE-NITROGEN	mg/l	2	3	<1.0	0.06[2]
NITRATE-NITROGEN	mg/l	<1.0	8	16	4[2]
NITRATE	mg/l	<1.0	36	72	18[2]
TURBIDITY	NTU	12	4	<1	<1

1. From Miller, C.J. 1990. Impact of Artificial Recharge on Tucson Area Groundwater Quality. Unpublished M.S. Thesis, the University of Arizona, Tucson.
2. Courtesy Tucson Water.

Note 1. Data on this table were obtained during this study except as noted below:

Note 2. The nitrogen data reported in the SAT column were obtained on samples of perched ground water. The remaining SAT data were obtained on water samples from the 15-foot lysimeter.

tertiary plant. As presently configured, the main function of this tertiary facility is the removal of suspended solids to maintain high infiltration rates on the spreading basins.

6.2 Dissolved Organic Matter

Our research has shown that SAT removes significant organic matter, whereas the tertiary plant has little effect on dissolved organic matter (Table 2). The treatment capacity of a SAT system will be limited mainly by the loading rate of the site which is affected by surface clogging following biofilm development. The pilot-scale SAT studies demonstrated that the near-surface decrease in DOC and TOX corresponded to a three-fold increase in the organic carbon content of the surface soil. This suggests that there may be an advantage in encouraging microbial activity in this zone, as opposed to periodically removing or otherwise disturbing surface soils for the purpose of augmenting infiltration rates.

6.3 Disinfection Byproducts

Based on test basin results, potable reuse may prove to be viable. However, while significant removal of organics is achieved, long term performance of SAT must be demonstrated. Table 2 shows that although THMs were greatly reduced by SAT compared to tertiary treatment, the THM formation potential (THMFP) remained high. The reasons for this are explained in Section 4.3.1. Thus, post treatment may be required to remove THM precursors and reduce THM levels to acceptable drinking water standards. [Currently, the standard for THMs is 100 micrograms per liter (parts per billion). However, EPA is considering lowering the standard to between 25 micrograms per liter and 50 micrograms per liter.]

6.4 Nitrogen

Nitrogen not converted to the nitrate form in the biofilter plant is converted to nitrate in the soil profile. Table 2 shows that nitrate levels in water samples collected from the shallow perched ground-water system exceed the current drinking-water standard of 10 milligrams per liter (parts per million) as nitrate-nitrogen (or 45 milligrams per liter as nitrate). The high levels of nitrate observed after infiltration through the soil mantle suggest that denitrification of either the source water or the recovered water may be required. However, the nitrate concentrations in recharging source water will be diluted by native ground water during recovery. Future sampling from deep lysimeters and from a monitor well in Basin 1 will further define the fate of nitrogen compounds.

PART 2: VIRUS REMOVAL STUDIES

SECTION 1. MICROBIAL RISKS

An important goal of SAT is to reduce the levels of disease-causing microorganisms. Disease-causing enteric viruses are usually present in municipal wastewater even after conventional secondary treatment and disinfection. The fate of viruses after land application of wastewater is of concern due to subsurface mobility of these small particles and their low infectious dose. Ingestion of only one virus particle could cause disease. Since secondary-treated sewage effluent may contain enteric viruses, additional treatment such as SAT can be useful in further reducing these concentrations. In the U.S. from 1971-1982, 99.6% of all cases of illness resulting from drinking ground water were of microbial or probable microbial origin.

For safe reuse, levels of enteric viruses must be reduced to levels that would avoid significant risk to public health. The state of Arizona has established standards for viruses for safe reuse of wastewater for irrigation and recreational purposes. Safe reuse also means minimizing the need for chlorine to kill pathogens. Disinfection byproducts include chlorinated hydrocarbons that have the potential to cause cancer if ingested. We expect that SAT will reduce precursors of disinfection byproducts (see Part 1), as well as pathogenic microbes, so that minimal further treatment will be necessary to produce water that meets all chemical and biological requirements for potable use.

SECTION 2. OBJECTIVES

Studies using chemical and microbial tracers in secondary and tertiary effluent were undertaken at the Sweetwater Underground Storage and Recovery Facility, Tucson, Arizona, to duplicate conditions expected during full-scale recharge at the site. Objectives of these studies included the following:

- Study virus removal by SAT. Filtration, sorption, and biodegradation processes in the soil can be expected to reduce microbial and other contaminants in sewage effluent. Quantifying the degree of removal is important in comparing SAT to other treatment options. Bacteriophages were chosen as models for pathogenic virus. Tracer viruses also mimic transport characteristics of other colloidal particles of concern that may facilitate transport of adsorbed chemicals. Colloidal particles may be transported faster than chemical tracers due to size exclusion from smaller pores.

- Compare transport of two different viruses (MS2 and PRD1) in recharged water. MS2 bacteriophage is a small virus (28 nm diameter), which is electro-statically repelled from soil solids at pH greater than 3.9. Small pathogenic viruses such as poliovirus are less repelled, so MS2 may be

considered a worst case for soil removal of small viruses. PRD1 bacteriophage is a large virus (62 nm diameter), which is electro-statically repelled from soil solids at pH greater than 4. Large pathogenic virus such as rotavirus are less repelled, so PRD1 may be considered a worst case for soil removal of large viruses.

- Compare transport of viruses to a conservative tracer (bromide) in recharged water. Bromide ion is not degraded or sorbed to any extent by passing through soil and, therefore follows the path of the infiltrating effluent. By tracing bromide concentrations, velocity of water percolation and the degree of hydrodynamic dispersion can be determined. Water velocity can be compared to virus transport rates and concentrations to calculate virus sorption, dispersion, and degradation. These parameters are essential to modelling virus movement in the subsurface. Bromide also mimics transport characteristics of nitrate and other small, low-interaction compounds. Soil water velocity may be estimated from bromide breakthrough curves.

- Study the effects of infiltration rate on virus removal. As infiltration is reduced by surface plugging, the larger soil pores drain, resulting in unsaturated flow. This condition alters water flowpaths and may affect virus removal.

- Contrast the effects of secondary and tertiary effluent on virus removal during SAT. Tucson Water is currently recharging tertiary effluent. However, overall costs might be reduced if SAT of secondary effluent produces recovered ground water of a quality similar to that produced during recharge of tertiary effluent. Raw effluent entering the county's Roger Road Wastewater Treatment Plant is treated by biofilters and chlorinated. The secondary effluent contains large biocolloids that protect encapsulated or adsorbed virus from chlorination and increase soil-surface clogging. Tertiary effluent is produced from secondary effluent by filtration through a mixed media of coal and sand at Tucson Water's Roger Road Reclaimed Water Treatment Plant. This treatment removes large biocolloids and some dissolved organic molecules.

SECTION 3. VIRUS REMOVAL STUDY METHODS

Two minibasins, 12 feet by 12 feet square, were constructed in Basin 1 at the Sweetwater Underground Storage and Recovery Facility. One minibasin was used for secondary effluent, and the other was used for tertiary effluent (Figure 1). Three tests with secondary and three with tertiary effluent were conducted. Infiltration rates declined during each test and were partially restored between tests when the mini-basin surface was allowed to dry. For the secondary effluent tests the maximum infiltration rates were 55, 6, and 3 feet/day. For the tertiary effluent tests, the maximum infiltration rates were 33, 9, and 4 feet/day. Water

samples were taken from the vadose zone to depths of 20 feet. Samples were also extracted from shallow wells as far as 150 feet from the minibasins. These wells accessed perched ground water at a depth of 14 feet depth.

SECTION 4. RESULTS

Results of the virus removal study are summarized in Table 3.

Bromide and virus arrived at sampling depths in an irregular pattern, indicating a high degree of preferential flow in these layered alluvial sediments. Nevertheless, the following results were obtained:

- Virus removals from 65 to 99% can be expected by passage of effluent through 12.5 ft of sandy alluvium, depending on virus type, flowrate, and pretreatment of the effluent.

- Virus transport velocities relative to bromide transport depended on the hydrologic conditions. When tracers were applied with water on a drained basin, virus velocities were slower than bromide by a factor of 2.5 to 5. This may have been due to sorption of the virus. When tracers were applied to an existing pond that had formed a clogging layer, virus velocities were faster than bromide by a factor of 1.6 to 1.7. This may be due to diffusion of bromide throughout the soil profile, including the small pores that were not accessible to the virus due to pore size exclusion.

- MS2 showed less removal than PRD1 for short travel times and shallow sampling points. For secondary effluent at the highest infiltration rate of 50 feet/day, MS2 removal at the 12.5 foot depth was only 90%. This contrasts with PRD1 removal of 99%. There was less removal of PRD1 at distant sampling points possibly due to better survival in groundwater. PRD1 was detected in a shallow monitor well in the perched water zone 150 ft from the minibasin, although removal was 99.98%. MS2 was not detected in this well. These results may have been due to size differences; the larger PRD1 being more readily removed by the surface clogging layer but persisting longer once it reached the perched water zone. This illustrates the need to test several types of virus.

- Virus removal rate coefficients, which measure the rate of disappearance of virus with time, were greater for lower infiltration rates. At high infiltration, the average coefficients for all depths ranged from 0.10 to 0.64 feet/hr; at low infiltration the range was 0.18 to 1.44 feet/hr. This indicates that some mechanism besides longer travel time contributes to removal of virus during low infiltration rates.

Table 2: Summary of Virus Study

OBJECTIVE	PURPOSE	RESULTS AND CONCLUSIONS
Study virus removal by SAT.	To predict pathogenic virus removal by SAT	Based on the transport of the two "worst-case" viruses used during this study, virus removals greater than 65% can be expected after 12 ft of percolation.
Compare transport of bromide to viruses.	To determine if viruses move at a different rate through soil than chemical tracers	Viruses traveled slower than bromide when infiltrating a drained basin, apparently due to retardation of the viruses. Viruses traveled faster than bromide in pre-wetted basins, apparently because the viruses were excluded from the smaller, slow flow pores, accessible to diffusion of bromide.
Compare removal of two different viruses.	Virus surface chemistry and size could influence removal by soil	The larger virus had greater removal near the soil surface, due to factors that are unclear at this time, but persisted longer (i.e., lower dieoff rate), resulting in higher concentrations at distant points.
Study the effects of infiltration rate on virus removal.	To determine if virus removal is enhanced at low flow rates	Low infiltration rates resulted in greater virus loss than removal due to travel time alone.
Compare virus removal when recharging secondary and tertiary effluents.	To determine if pre-treatment of sewage influences virus removal	In general, greater removal occurred with secondary effluent for the virus concentrations used during our tests, possibly because the greater turbidity of secondary effluent facilitates sorption.

- Use of secondary effluent generally resulted in greater removal of virus than tertiary effluent. For secondary effluent with infiltration rates less than 40 ft/day, at least 85% removal of small virus like MS2 and 99% removal of large virus like PRD1 can be expected after unsaturated flow of effluent through 12.5 ft of sandy alluvium. Corresponding removals for tertiary effluent are 65% for MS2 and 85% for PRD1. Better removal from secondary effluent may be due to a thicker surface biocolloid layer formed from growth of microorganisms and accumulation of microbial products.

SECTION 5. CONCLUSIONS

The suite of tracers used in this study (bromide, MS2 bacteriophage, and PRD1 bacteriophage) appear to be appropriate for characterizing contaminant transport and removal processes during soil-aquifer treatment.

- Layered alluvial sediments created preferred flowpaths for transport of bromide and viruses. These heterogeneities in texture with depth may reduce the effectiveness of soil-aquifer treatment.

- The larger virus, PRD1, was more readily removed but persisted longer in groundwater. Consequently, larger viruses may be more likely to occur in water supply wells.

- For the virus concentrations used in our tests, about 15% greater virus removal occurred at the 12.5 foot depth with secondary effluent than with tertiary effluent.

PUBLICATIONS AND PRESENTATIONS

Publications

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Presentations

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GLOSSARY

Alluvial: Relating to the processes or materials associated with the transport or deposition by running water.

AMW: Apparent molecular weight.

Biocolloids: Colloidal microorganisms or particles produced by organisms, especially polysaccharides from sloughing of the secondary-treatment slime layers.

BOD: Biochemical oxygen demand. The quantity of oxygen used by a mixed population of microorganisms in the aerobic degradation of the organic matter in a sample waste water at a temperature of 20°C.

BLS: Below land surface.

Breakthrough curve: The relative solute concentration in the outflow from a column of porous medium after a step change in solute concentration has been applied to the inlet end of the column, plotted against the volume of outflow (often in number of pore volumes).

Colloidal particle: A suspended particle of approximately 10-1000nm diameter.

DBPs: Disinfection byproducts. Chemical compounds formed as a result of disinfecting sewage effluent, e.g., THMs, haloacetic acid, etc.

DOC: Dissolved organic carbon. A nonspecific parameter for all organic compounds; the organic carbon passing through a 0.45 micron silver or glass-fiber filter. DOC quantifies the chemically reactive fraction and gives the mass of organic carbon dissolved in a water sample.

DOM: Dissolved organic matter. DOM consists of both humic (hydrophobic) and nonhumic (hydrophilic) fractions. Alternatively, DOM consists of both low molecular weight (size) and high molecular weight (size) fractions.

f_{oc}: Fraction of organic carbon (mass of organic carbon per unit mass of soil, usually expressed as a percentage).

Humic substances: Humic substances are naturally-occurring dissolved organic matter (DOM), derived from decaying vegetation.

Hydrodynamic dispersion: The process wherein the solute concentration in flowing solution changes in response to the interaction of solution movement with the pore geometry of the soil, a behavior similar to diffusion but only taking place when

solution movement occurs. It is a measure of the degree of spreading of a tracer plume.

Hydrophilic: Having a strong affinity for water.

Hydrophobic: Lacking affinity for water.

Infiltration rate: The volume of water passing through the soil surface per unit cross-sectional soil area in unit time, with dimensions of length per unit time (e.g. $(ft^3/ft^2)/day = ft/day$).

Instantaneous THMs: This term refers to the concentration of THMs at the "instant" of sample collection. Continued formation can occur if a chlorine residual is present.

Instantaneous TOX: This term refers to the concentration of TOX at the "instant" of sample collection. Continued formation can occur if a chlorine residual is present.

Lysimeter: A device for sampling pore liquid from the vadose zone. also called suction sampler.

Mutagen. Substances that cause cells to mutate. Mutagenic substances may produce cells that are cancer producing.

MS2 bacteriophage: A bacterial virus (28 nm diameter) which does not infect or cause disease in humans or animals.

NPOX: Non-purgeable organic halide.

Pathogenic: Able to cause disease in humans.

Perched water: A water-saturated layer in the subsurface, above the regional water table, that is maintained by sufficient percolation to offset loss through a lower, slowly permeable layer.

PRD1 bacteriophage: A bacterial virus (62 nm diameter) which does not infect or cause disease in humans or animals.

POX: Purgeable (volatile) organic halides.

Preferential flowpaths: Water flow routes through soil in concentrated regions (e.g., root holes, cracks) rather than throughout the entire profile.

Primary effluent, raw effluent: Untreated sewage water.

Removal rate coefficient: The first-order specific removal rate (u) with dimensions of 1/time defined by: $C = C_o \exp(-u\ t)$, where C is virus concentration at a given depth, C_o is pond concentration, and t is time.

SAT: Soil-aquifer treatment. Treatment of sewage effluent by processes such as sorption and biological activity during

percolation through the vadose zone and mixing with ground water below the water table. The term Rapid Infiltration and Recovery (abbreviated as RIX) is used elsewhere for this process.

Secondary effluent: Trickle biofiltered and chlorinated sewage effluent from Pima County's Roger Road Treatment Plant.

Size exclusion: A filtering process that keeps colloidal particles in the larger soils pores. Water velocity is proportional to the square of the pore radius by Poiseuille's Law, resulting in faster transport of colloidal particles.

Tertiary effluent: Secondary effluent filtered through coal and sand mixed media at Tucson Water's Roger Road Reclaimed Water Treatment Plant. In this report, the term "reclaimed water" is synonymous with tertiary effluent.

THMs: Trihalomethanes. THMs are halogenated methanes formed upon chlorination of precursor compounds such as humic substances. Chloroform is an example of a THM.

THMFP: Trihalomethane Formation Potential. THMFP is a term for the "potential" formation of THMs under a prescribed set of chlorination conditions after a designated reaction time.

TOX: Total Organic Halide. TOX is a nonspecific parameter for halogenated (chlorinated) organic compounds.

TOXFP: Total Organic Halide Formation Potential. TOXFP is a term for the "potential" formation of TOX under a prescribed set of chlorination conditions after a designated reaction time.

Unsaturated flow: The movement of water in soil in which the pores are not completely filled with water.

Vadose zone: The geological material overlying a water table.

Wastewater: Primary or secondary effluent.

THE ROLE OF SOIL AQUIFER TREATMENT (SAT) IN WASTEWATER RECLAMATION/REUSE; HYDROLOGICAL, CHEMICAL, AND MICROBIOLOGICAL CONSIDERATIONS

PHASE 2

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INTRODUCTION

Phase 1 of this research project was a field study conducted at the Sweetwater Underground Storage and Recovery Facility under contract to Tucson Water and the Salt River Project. The general purpose of the study was to determine the fate of organic compounds, nitrogen, and viruses during soil aquifer treatment (SAT) of secondary and tertiary effluent. The field study showed that both dissolved organic carbon (DOC) and total organic carbon (TOX) were reduced during SAT. Average DOC and TOX removals amounted to about 50% and 40%, respectively. Nitrate pulses, similar to those observed in other SAT studies, were noted in the profile at the beginning of wetting cycles. Total nitrogen losses amounted to about 25%. Virus removals exceeding 65% were observed in applied effluent after 12 ft of percolation through the vadose zone.

The processes governing the fate of total organic halide (TOX), dissolved organic carbon (DOC), nitrogen, and virus residuals could not be differentiated during the field studies. The dominant processes are abiotic (primarily sorption) and biological (biodegradation) in nature. Identifying the relative effectiveness of these processes is important in designing SAT facilities. That

is, sorption is essentially a finite process, while biodegradation is a renewable process. Consequently, Phase 2 experiments were designed to separate biological and abiotic components by simulating SAT in laboratory columns.

OBJECTIVES

Specific objectives of Phase 2 are as follows:

- o Conduct laboratory column studies to determine the removal of organics under abiotic versus biotic conditions
- o Conduct laboratory column studies to determine the removal of animal viruses versus bacteriophage removal
- o Conduct laboratory column studies to determine the removal of Cryptosporidium parvum during SAT
- o Conduct laboratory studies to evaluate the optimization of effluent chlorination relative to the following:
  - o TOX formation versus degree of chlorination
  - o Effects of ammonia
  - o Formation of other disinfection by-products versus chlorination
- o Conduct field studies in Basin 1 to determine the depth-wise distribution of organic and inorganic chemicals during the 1991-1992 recharge season.

METHODS AND RESULTS

Work is still in progress. Preliminary results follow:

1. Organic Fate Studies

One-meter stainless steel columns were constructed and packed with soils from the Sweetwater facility in order to simulate soil aquifer treatment in moderate-scale reactors under lab conditions. Water sources included secondary and tertiary effluents. One set of columns was flooded with source waters as received to simulate biotic conditions. A control column was flooded with sterilized (inhibited) source water to simulate abiotic conditions.

The summary data suggest that:

- o Simulated SAT removes 40% of the residual DOC in secondary-treated wastewater;
- o The efficiency of DOC removal from tertiary effluent is significantly lower, on the order of 25-30 percent;
- o Removals of DOC in the inhibited control were 10% suggesting that the bulk of the DOC losses in the secondary and tertiary columns were biologically driven.
- o Both the biologically active (secondary) and inhibited columns removed 10-20 percent of the influent TOX, suggesting that the mechanism for TOX removal is abiotic in nature.

2. Virus studies

The following table summarizes column studies to determine the fate of viruses during SAT:

Objective	Purpose	Conclusion
Unobstructed vs Clogged Soil	To evaluate how clogging, which occurs in infiltration basins, affects virus removal	From 3 to 10 times less virus were transported under clogged conditions where infiltration rates were 6 to 37 times less.
Secondary vs Tertiary Effluent	To determine the effect of effluent on virus removal	Removal from secondary effluent was equal to or greater than removal from tertiary effluent
Saturated vs Unsaturated Flow	To quantify the importance of unsaturated zone depth on virus removal	From 3 to 25 times less virus were transported under unsaturated flow.
Poliovirus vs Bacteriophage Removal	To extend phage field data to a human virus	Polio removal was initially greater, but decreased to the phage level after about 7 pore volumes
Batch Adsorption Test	To determine relative adsorption of the viruses, and if batch studies could be used to predict virus removal in soil columns	MS2 and PRD1 were poorly adsorbed. Poliovirus was adsorbed 26 to 99 times more strongly.

Bacteriophages MS2 and PRD1 and Poliovirus were applied to 1 m long columns of "Sweetwater" soil.

3. Field studies:

Field studies were conducted in Basin 1 of the Sweetwater Underground Storage and Recovery Facility. Monitoring facilities include two identical sets of ceramic suction lysimeters ranging in depths from 2.5 to 80 ft below the floor of the basin, and a 206 ft deep monitor well. The monitor well includes a packer assembly permitting sampling near the water table. The purpose of the

monitoring studies was to monitor the following during the 1991-1992 recharge season:

- o organics removal (as measured by TOX and DOC),
- o nitrogen speciation during deep percolation and recharge of applied tertiary effluent, and
- o trends in concentrations of the major inorganic anions and cations during deep percolation and recharge of applied tertiary effluent.

In terms of organics, infiltration through 80 ft of the vadose zone reduces DOC levels to about 20% of applied (recharge basin) levels. In comparison to our previous work with the mini-basins, where we observed DOC reductions of 50% over 20 ft of soil, this represents some additional treatment afforded by lower depths of the vadose zone.

The dominant nitrogen species in source water is NH_3-N, while NO_3-N was essentially the only species found in ground water. Total nitrogen in source water averaged about 23 mg/l. The total nitrogen content of monitor well samples averaged about 14 mg/l. Thus, the loss in total nitrogen through the vadose zone profile was about 39 percent. Possible mechanisms for this loss are denitrification and dilution. Among other factors, denitrification requires anaerobic conditions. The region where this most likely occurs is a shallow perched ground-water zone above 17 ft.

Recharging tertiary effluent decreased the total dissolved solids (TDS) content of ground water near the water table. Recharging river water during Spring flows in the Santa Cruz River may also have diluted ground water. Toward the end of the recharge season, specific conductance (EC) values approached source water levels.

PHOENIX ZERO DISCHARGE PLANS

Oralynn Self
Greeley & Hansen

Mike Gritzuk
City of Phoenix

3:15 pm -- 3:50 pm

CITY OF PHOENIX, ARIZONA
RECLAIMED WATER FEASIBILITY STUDY
ON-SITE STORAGE FACILITY INVESTIGATIONS AND FACILITY PLANNING
1992

Wallace A. Ambrose, Partner
Greeley and Hansen

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City of Phoenix Water Services Department

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1. INTRODUCTION

The Subregional Operating Group (SROG) consists of the six cities that contribute wastewater to the 91st Avenue regional wastewater treatment plant (WWTP). Glendale, Mesa, Phoenix, Scottsdale, Tempe and Youngtown are responsible for the effluent discharging to the Salt River. The regional WWTP Total Effluent Reuse Study evolved from the concern over the potential cost of upgrading existing treatment processes at the WWTP to meet the more stringent National Pollutant Discharge Elimination System (NPDES) permit and the proposed State draft Navigable Water Quality Standards (NWQS). The initial Phase I Technical Feasibility Study, has been completed. The subsequent Phase II site-specific investigations are now underway. The Phase III effort, comprising the underground storage of excess effluent generated from the 23rd Avenue WWTP, is also now in progress.

The objective of the Phase I study was to determine if there was a cost-effective, technically feasible alternative to continued discharge to the Salt River. In addition to defraying some of the expected high costs of treatment upgrades, an alternative which includes reuse of the effluent may also provide the cities with potential water credits. The effluent currently discharged to the river is unrecoverable by the cities. Although users located downstream of the regional WWTP may utilize the effluent as surface water for irrigation, etc, the cities cannot because they are all located upstream of the plant. However, effluent that is stored underground and subsequently recovered can be of benefit to the cities. Recent legislation may make it possible to trade the effluent used to replenish groundwater for surface water credits. Similarly, trading the recoverable water to an irrigation district for its Central Arizona Project (CAP) (Colorado River water) rights provides flexibility which can also directly benefit the cities.

Initially, research was conducted into existing documents to establish background material for subsequent evaluation of study alternatives. Information was reviewed and compiled in the following areas of study:

- Survey of zero discharge WWTPs in the United States.
- Biomonitoring summary.
- Regulatory considerations.
- Historic effluent uses at the regional WWTP.
- Historic effluent volumes at the regional WWTP.
- Consumptive use of water by crops.
- Reclaimed water quality impacts on agronomics.
- Health effects of reclaimed water use.
- Public opinion and socioeconomic factors regarding reuse.
- Injection well feasibility.
- Preliminary hydrogeologic evaluations of irrigation and underground storage of effluent.
- Reclaimed water alternatives.
- Baseline alternative treatment process options.

This material served as a basis for evaluations which resulted in the conclusions and recommendations contained in the feasibility report.

The Reclaimed Water Technical Feasibility Study addressed the following:

- Background of the regional WWTP, including effluent flows and effluent uses.

- Identification of the baseline alternative for the treatment processes required at the regional WWTP to meet new regulations for discharge into the Salt River.

- Identification of the reuse alternatives, addressing regulations, type of reuse, and uses of water.

- Conclusions and recommendations.

2. BACKGROUND

2.1 Regional WWTP

The 91st Avenue regional WWTP was constructed in 1958, with an initial capacity of 5 mgd. The wastewater was treated through a secondary treatment process, incorporating a process similar to that which is currently in use to produce an effluent that discharged into the normally-dry Salt River.

The regional WWTP has since been upgraded and expanded to its current capacity of 153 mgd. The secondary effluent is discharged to the Salt River. The plant has consistently met its NPDES permit requirements.

The NPDES permit expired in 1991, and what was the draft permit, requiring more stringent quality limitations on the effluent, is now in effect with some modifications. Significant treatment modifications of process would have been required to meet the proposed permit requirements.

In addition, the Arizona Department of Environmental Quality's (ADEQ's) new NWQS are even more limiting than the NPDES permit requirements.

To evaluate potential reuse alternatives, historic effluent flow patterns and effluent uses were researched. Although the effluent flow from the regional WWTP relates directly to the influent flow, two contractual use requirements of the effluent are variable and, therefore, not predictable.

2.2 Effluent Uses

The two contractual effluent users, Buckeye Irrigation Company and Arizona Nuclear Power Project, account for most of the effluent use and are the only users addressed here:

- The Buckeye Irrigation Company (BIC) negotiated a contract in 1971 with the City of Phoenix to allow the BIC to acquire effluent from the river for 40 years until 2011. The actual contracted amount is 2,500 acre-feet (AF) per month, or 30,000 AF/year (approximately 26.7 mgd average). The BIC delivers irrigation water to approximately 18,000 acres of the Buckeye Water Conservation and Irrigation District. The crops in this region consist primarily of cotton. The irrigation demand of the Buckeye District is highly variable with the season. Cotton has virtually no demand for water from November through February. During the summer, water demand typically peaks in July with an approximate average of 15 AF/month/acre.

- The Arizona Nuclear Power Project (ANPP), a nuclear steam electrical generating station, negotiated a contract in 1973 with the SROG cities for rights to effluent. The ANPP has an option of up to 140,000 AF/year (approximately 125 mgd). This is based on the operation of five generating units. However, three units were initially constructed and are currently operating. There is no plan in the near future to construct the additional two reactors. The effluent usage fluctuates with the cooling water demand of the units which is influenced by the time of the year and maintenance shutdowns.

2.3 Effluent Flow

The 91st Avenue regional WWTP is an "end-of-line" facility. The participating cities, Phoenix, Glendale, Mesa, Tempe, Scottsdale and Youngtown, convey all or a portion of their wastewater to the plant.

The influent wastewater follows a diurnal pattern similar to that for a typical domestic WWTP. The effluent flow rate from the plant corresponds directly to the influent flow rate, but actual flow discharged to the Salt River is subject to the demands at the ANPP. For any reuse option to be feasible, all processes, pipelines, and other required appurtenances should be sized for the full regional WWTP flow, because, on occasion, the ANPP does not divert any effluent for its use.

3. BASELINE ALTERNATIVE

3.1 Introduction

The 91st Avenue regional WWTP had been operating under a NPDES permit that has been administratively extended by the Environmental Protection Agency (EPA). The initially proposed NPDES permit, however, had many more stringent limitations for effluent discharge into the Salt River, and the State's proposed NWQS further impacted the required water quality. The baseline alternative comprises the facilities necessary to allow the continued discharge of treated wastewater to the Salt River, and meet the requirements of the initially proposed NPDES permit. Because the NWQS will comprise the basis for the next generation of the NPDES permit, the assessment of the baseline alternative must also address the quality requirements for the proposed NWQS.

Currently, the segment of the Salt River downstream of the regional WWTP has uses for aquatic and wildlife, incidental human contact, agricultural irrigation and agricultural livestock watering. The Salt River is classified as an effluent-dominated stream from the City of Phoenix's 23rd Avenue WWTP, upstream of the regional WWTP, to the confluence of the Gila River downstream of the regional WWTP. Water quality standards are developed on a case-by-case basis for effluent-dominated waters.

3.2 Water Quality Limitations and Regional WWTP Performance

The water quality limitations of the draft NPDES permit and the proposed NWQS were evaluated by comparing them to the historic water quality data from the regional WWTP from 1989 and 1990. The data consist of quarterly monitoring data for metals, volatile organics, acid extractable organics, base/neutral extractable organics, organochlorine, pesticides, and PCBs. Operations information from 1990 was used to assess the potential of the existing treatment process to meet the draft NPDES and the proposed State navigable water quality requirements.

3.2.1 Draft NPDES Permit

The draft NPDES permit specified limitations for the following constituents:

- Biochemical oxygen demand (BOD)
- Suspended solids (SS)
- Fecal coliform bacteria
- Viruses
- Chlorine
- pH
- Metals and trace substances
- Phenolic compounds
- Dissolved oxygen
- Toxicity

The draft NPDES permit specified average monthly BOD and SS concentrations of 25 mg/L and 30 mg/L, respectively. The maximum BOD and SS limits recorded during 1990 for the regional WWTP were 23 mg/L and 17 mg/L, respectively. For these two limitations, no additional treatment was recommended to meet the draft NPDES permit.

The permit criteria for fecal coliform bacteria, an indicator of disease-producing organisms, set a daily maximum discharge limit of 4,000 MPN/100 ml and monthly average of 1,000 MPN/100 ml. During 1990, the plant effluent readily met these requirements, recording a maximum daily concentration of 920 MPN/100 ml. No process modifications were necessary to meet this standard.

The draft NPDES permit established a stringent discharge limitation of virus at one unit/40 L. The effluent from the regional WWTP has not been sampled by the City of Phoenix for viruses. Based on typical virus counts in secondary effluent, the treatment processes that are currently in place may not reliably meet the enteric virus standard. To meet this standard, filtration and extended disinfection would need to be added.

Chlorine is toxic to aquatic life in small quantities. A chlorine discharge level of 0.05 mg/L was listed in the draft NPDES permit to prevent the discharge of a chlorine dose that would be toxic to aquatic life in the Salt River. Because the regional WWTP uses chlorine for disinfection, the effluent contains some chlorine residual. Typical effluent chlorine concentrations observed ranged from 2 to 4 mg/L, with a maximum chlorine residual of 6.9 mg/L. Dechlorination would need to be added following disinfection to lower chlorine residual.

The allowable effluent pH, as stated in the draft NPDES permit, was between 6.5 to 9.0. The effluent pH in 1990 was recorded between 6.2 and 7.6, averaging 7.0. Depending on other treatment processes required, pH control may be required to maintain the pH above the 6.5 limit.

The draft NPDES permit set numerical limitations for metals and trace substances. Copper has been monitored at the permit limitation of 0.05 mg/L only once out of 48 samples taken from 1989 to 1990. The concentration of the sample at limit was 0.051 mg/L. No metal or trace substance exceedance was noted. Water quality data for metals and trace substances are limited from the regional WWTP. No additional treatment appeared necessary for metals or trace substance removal nor was any recommended.

Nearly all of the phenolic compounds were reported as "not detected" in water quality information obtained from the regional WWTP. One observation of phenol was observed at a concentration of 0.0117 mg/L, which is below the limitation of 2.56 mg/L set forth in the draft NPDES permit. Based on available data, there was no apparent need for incorporating additional treatment to remove these compounds.

As stated in the draft NPDES permit, the effluent discharge must not decrease the dissolved oxygen (DO) concentration in the receiving water (Salt River) to less than 1.0 mg/L. The regional WWTP effluent has an oxygen demand, as the addition of a dechlorination chemical will consume DO, resulting in the necessity for reaeration of the effluent prior to surface discharge.

Biomonitoring was included as a requirement in the draft permit for three reasons, according to the EPA:

- Municipal POTWs are cited as potential sources of toxic discharges.
- Lack of dilution in the receiving waters of the Salt River.
- Historic test data show acute toxicity in the discharge.

The EPA has concluded that numerical limits alone will not ensure attainment and maintenance of the water quality standards.

Data from acute and chronic biomonitoring tests previously performed have demonstrated toxicity in the effluent from the regional WWTP. Those studies suggested that ammonia may have caused chronic and acute toxicity responses, although other constituents may also have had an effect. Previous experiments conducted at the City of Phoenix 23rd Avenue regional WWTP have indicated that a reduction in ammonia resulted in relatively low toxicities in the final effluent. Therefore ammonia control was recommended at the regional WWTP.

The following treatment process modifications to the regional WWTP are required for the effluent to comply with the draft NPDES permit and continue to discharge into the Salt River:

- Ammonia Removal: This can be accomplished using a single-stage nitrification/denitrification system through modification of the existing aeration basins.

- Virus Inactivation: To achieve the proposed virus limit, four process facilities were recommended:

  - Alum coagulation
  - Flocculation (to aid filtration)
  - Filtration
  - Increased chlorine contact time (2 hours)

  NOTE: Metals removal would also be enhanced by these modifications.

- Dechlorination: Use of sodium bisulfite was recommended to decrease chlorine residual.

- pH Control: Nitrification and alum coagulation processes can depress pH below 6.5. Sodium hydroxide addition was recommended to increase pH to within discharge limits.

- Reaeration: Reaeration, with mechanical aerators, can maintain at least 1.0 mg/L of DO in the receiving stream.

A process schematic of the baseline process train to meet the proposed NPDES water quality requirements is shown on **Figure 1**.

3.2.2 Proposed Navigable Water Quality Standards

The numerical water quality standards in the proposed NWQS were generally more stringent than the limitations set forth in the draft NPDES permit.

All treatment modifications required for the draft NPDES permit were also recommended to meet the proposed NWQS. The proposed NWQS was different from the draft NPDES permit in three areas, including:

- Virus/pathogenic organisms
- Metals
- Organic compounds

Although virus/pathogenic organisms limits were proposed to be removed from the proposed NWQS, more restrictive fecal coliform levels would most likely be added. Fecal coliform bacteria can be removed by the same processes as those required for virus inactivation.

The capability to remove metals would likely be required. Quarterly sampling data for 1989 and 1990 indicated four metals potentially identified in the proposed NWQS: antimony, arsenic, selenium and silver. These metals can be removed by alum precipitation/coagulation and filtration, with tertiary sedimentation recommended to decrease solids in the process.

Many organic compound limitations are included in the proposed NWQS. Based on available water quality data, only two organic compounds were observed in the effluent: alpha-BHC and gamma-BHA (lindane). Organic removal process requirements are significant, considering the benefits derived. Air stripping was recommended to remove volatile organic compounds. Granular-activated carbon (GAC) contactors would follow, to remove semivolatile and nonvolatile organic compounds. In a plant the size of the 91st Avenue regional WWTP, carbon regeneration on site is less costly than off-site disposal.

The schematic of the process train recommended for compliance with the proposed NWQS is shown on **Figure 2**.

3.3 Costs

The opinions of probable costs for the baseline alternative are presented in **Table 1.** The costs are shown for compliance with the draft NPDES permit and compliance with the proposed NWQS. The costs are further broken down by process, capital, and operation and maintenance items.

The draft NPDES permit compliance capital cost of $98 million is less than the proposed NWQS compliance cost at $368 million. However, the proposed NWQS compliance costs represent the probable real cost of plant upgrades at the regional WWTP since the plant will ultimately be required to comply with the proposed NWQS when they are incorporated into the next generation of the NPDES permit. Despite this costly array of capital improvements at the regional WWTP,

the effluent discharged into the Salt River would remain a nonrecoverable resource by the SROG cities.

4. REUSE ALTERNATIVES

4.1 Introduction

The baseline alternative represents an alternative that continues to discharge effluent from the 91st Avenue regional WWTP to the Salt River, while complying with the draft NPDES permit and the proposed NWQS. No water credit is received for discharging the excess effluent, since the water is nonrecoverable by the cities. Reuse offers an efficient water resource management option to continued surface discharge into the river and one which could avoid the cost of continuing upgrades to the WWTP's treatment processes.

Reuse alternatives were developed based on technical feasibility and potential cost benefit. The alternatives included direct reuse options and underground storage/recovery options. To avoid the costs of compliance with the draft NPDES permit or the proposed NWQS, reuse options were based on zero discharge - 100 percent reuse.

4.2 Direct Reuse Options

Direct reuse involves directly applying plant effluent, as it is delivered from the WWTP, for irrigation. Irrigation districts in central Arizona could potentially use all excess effluent for crop irrigation. The annual irrigation water demand of the various districts exceeds the effluent production at the regional WWTP. The peak irrigation demand occurs in the summer. Accomplishing 100 percent reuse by the irrigation districts would require either an extensive distribution system to convey effluent to many geographically diverse locations during the winter, or a storage facility to hold effluent during winter for use during peak summer months by a more localized group of users.

Because of the seasonal nature of the demands, direct reuse disposal of all excess effluent generated at the regional WWTP was eliminated from further consideration. However, direct reuse can be combined with underground storage and recovery.

4.3 Underground Storage and Recovery

Underground storage and recovery comprises percolating or injecting effluent below the ground surface into aquifers for storage and subsequent recovery and reuse.

After substantial prescreening of many sites, six underground storage and recovery alternatives were developed. Each alternative comprised the use of different underground storage site locations. Each alternative accommodated the continued discharge to the ANPP, direct reuse by the (BIC), other direct reuse sites at irrigation districts, and underground storage and recovery (USR) sites.

Of the six underground storage and recovery alternatives evaluated, one alternative was determined to be the most cost effective and technically feasible and, therefore, became the preferred alternative.

4.4 Preferred Alternative

The preferred alternative encompasses the following accommodations and characteristics:

- Continued variable effluent discharge to ANPP.
- Effluent supplied to the BIC, upon demand, via the BIC interface on the ANPP pipeline.
- System capable of accommodating underground storage/recovery of all excess effluent.

The criteria for selection of an underground site included favorable soil for percolation, adequate storage volume for 200 mgd of effluent for 10 years assuming no recovery, areas located outside of any river channel (to avoid an NPDES permit), and relative proximity to the regional WWTP.

The preferred reuse alternative, including underground storage/recovery, accommodates the following considerations:

- Conveyance of excess effluent from the 91st Avenue regional WWTP to the underground storage/recovery site. A new effluent pump station at the regional WWTP site and force main would be sized for 200 mgd. The pipeline would be routed via public right-of-way to minimize easement acquisitions. Construction of equalization basins at the regional WWTP was recommended to minimize flow variations.
- The effluent would be percolated into the aquifer using rapid infiltration basins (RIBs). The RIBs would be constructed outside the boundaries of the 100-year flood plain. Access roads, flood control and berms would be used to prevent any surface discharge from the site.
- The effluent quality required by the ADEQ prior to percolation is achievable from the current treatment processes at the 91st Avenue regional WWTP. However, soil treatability for nitrates may be unreliable. Accordingly, capability for biological nitrogen removal at the regional WWTP to achieve acceptable nitrate levels was recommended. The proposed treatment schematic is shown on **Figure 3**.
- The land required for RIBs was estimated using percolation rates common to the soils in the percolation site area. However, subsequent boring and percolation pilot testing will be necessary before actual land requirements can be accurately determined.

- The City of Phoenix has a contract with the BIC to supply irrigation water. This effluent would be conveyed through the BIC interface on the ANPP pipeline to avoid any surface water permits. Current regulations for effluent reuse require disinfection. Accordingly, chlorination facilities were recommended at the interface.

- The ADEQ and the Arizona Department of Water Resources (ADWR) require an Aquifer Protection Permit (from the ADEQ) and an Underground Storage Permit (from the ADWR) for this type of project.

Opinions of capital, and operation and maintenance costs for the preferred alternative are presented in **Table 2.**

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The 91st Avenue regional WWTP Reclaimed Water Phase I Technical Feasibility Study resulted in the following conclusions:

- The regional WWTP can be upgraded to meet the draft NPDES permit and the proposed State Navigable Water Quality Standards at probable capital costs of approximately $98 million and $368 million, respectively. Corresponding total annual costs, including amortization of capital costs, are approximately $17.5 million and $51.2 million, respectively.

- Zero discharge can be achieved through an underground storage project at a probable capital cost ranging from $70 million to $152 million depending on percolation rates at individual storage sites and resultant acreage requirements. Corresponding minimum and maximum total annual costs, including amortization of capital costs, are approximately $12.7 million to $21.3 million, respectively. *The costs identified herein do not include cost of recovery.*

5.2 Recommendations

The following recommendations were made as a result of the Reclaimed Water Phase I Technical Feasibility Study:

- Begin a Phase II Site-Specific Study to determine land areas and locations required to implement an underground storage project in the preferred storage site location. This study, now underway, includes:

  - Soil borings
  - Well inventory
  - Water quality sampling
  - Bench treatability studies
  - Pilot percolation testing

- Proceed with the biological nitrogen removal project at the 91st Avenue regional WWTP.

- Meet with the EPA and the ADEQ to discuss the impacts of total effluent reuse on the NPDES permit requirements.

- Study water recovery/water rights issues to maximize ownership/credits for the cities.

6. PHASE II - SITE-SPECIFIC STUDIES

6.1 Soil Borings

Soil boring investigations are currently underway. Among the data to be gathered are:

- Soil permeability
- Thickness of spoil material
- Depth to groundwater
- Depth/thickness of restricting layers
- Extent/cost of site improvements
- Vadose zone soils treatment capability

6.2 Well Inventory and Select Water Quality Sampling

A well inventory in and adjacent to certain prospective reclaimed water percolation is currently being compiled. From this inventory, select wells will be tested for inorganic chemical content and for pollutants consistent with EPA Method 601 analysis testing. The selection of the wells for water quality sampling will be accomplished in concert with ADEQ representation. The purpose of the groundwater quality sampling will be to establish a baseline water quality of the local groundwater before percolation of effluent is initiated.

6.3 Soils Treatability Studies

Based on the results of the soil borings and the select water quality sampling, soils treatability studies will be performed in three components, including:

- Historic soils treatability studies in the area around the 91st Avenue WWTP. The purpose of this study will be to assess the effectiveness of the soils to remove nitrogen and other contaminants. Because there is limited infiltration around the 91st Avenue WWTP, the benefits derived from this component of study may be limited.

- Bench treatability studies of reconstructed soil samples taken from the preferred percolation site will be conducted. The purpose of these studies will be to assess the treatability of the soils in the preferred percolation area. It will also be to assess the benefit of managing the composition of the top two or three feet of percolation soils to maximize the percolation basin.

- Review prior local treatability studies. The purpose of this component will be to make use of years of prior percolation studies performed by the U.S. Department of Soils Conservation.

6.4 Full-Scale Pilot Percolation Testing

A full-scale pilot percolation test basin will be constructed on the preferred percolation site. The purpose of the tests will be to establish the design criteria for the final design of the percolation basins on the preferred site.

7. PHASE II - FACILITY PLANNING

7.1 General

To accommodate convenient transition into the design of the reclaimed water facilities, a facilities plan will be developed that will establish the final design criteria and site location for:

- Equalization and reclaimed water pumping and conveyance system

- Reclaimed water percolation ponds

8. PHASE II - PLAN OF IMPLEMENTATION

8.1 General

It is anticipated that the City of Phoenix for or with other SROG cities may be required to enter into consent order negotiations with the U.S. EPA. The purpose of the negotiation would be to mitigate possible noncompliance with the new NPDES permit at the 91st Avenue WWTP. Among what is being prepared as part of the plan of implementation are:

- Regulatory requirements
- Denitrification of construction components
- Construction staging
- CPM schedule
- Real estate/easement procurement
- Financing alternatives
- Environmental assessment scope
- Public information preparation

9. PHASE III - 23RD AVENUE WWTP - DISPOSAL OF EXCESS EFFLUENT

9.1 General

The City of Phoenix is currently considering a multi-party agreement that would utilize effluent from the 23rd Avenue WWTP for direct use irrigation. It is likely that the demands of the prospective user will vary seasonally over a 12-month period. To achieve the elimination of all surface discharge from the 23rd Avenue WWTP, the City is interested in conveying all excess effluent from the 23rd Avenue WWTP to the same underground storage facility proposed for percolating the effluent from the 91st Avenue WWTP. How this will be accomplished is the objective of the Phase III effort. The product of the Phase III effort will be a facility plan report.

CITY OF PHOENIX, ARIZONA
TOTAL EFFLUENT REUSE STUDY

Table 1: Baseline Alternative Processes - Costs

Item	Costs ($ Million)	
	Draft NPDES Permit	Proposed NWQS Standards
Capital Costs		
1. Nitrogen Removal Modifications	7.95	7.95
2. Chemical Addition/Flocculation[1]	16.50	16.50
3. Tertiary Sedimentation	--	17.09
4. Filtration	36.96	36.96
5. Air Stripping[1]	--	87.49
6. Granular Activated Carbon[1]	--	164.90
7. Disinfection	31.51	31.51
8. Dechlorination and pH Adjustment	1.35	1.35
9. Reaeration	4.03	4.03
TOTAL[2]	98.30	367.78
ANNUAL COSTS[3]	10.00	37.50
Annual Operation and Maintenance Costs		
1. Power	1.53	2.91
2. Chemicals	5.16	9.39
3. Labor	0.78	1.13
4. Materials	0.06	0.23
TOTAL O&M COSTS	7.53	13.66
TOTAL ANNUAL COSTS	**17.53**	**51.16**

1. Includes pump station.
2. Includes contingencies, engineering fees, administration.
3. Amortized over 20 years at 8 percent.
4. Annualized capital costs plus annual operation and maintenance costs.

CITY OF PHOENIX, ARIZONA
TOTAL EFFLUENT REUSE STUDY

Table 2: Total Reuse Alternative Processes - Costs ($ Millions)

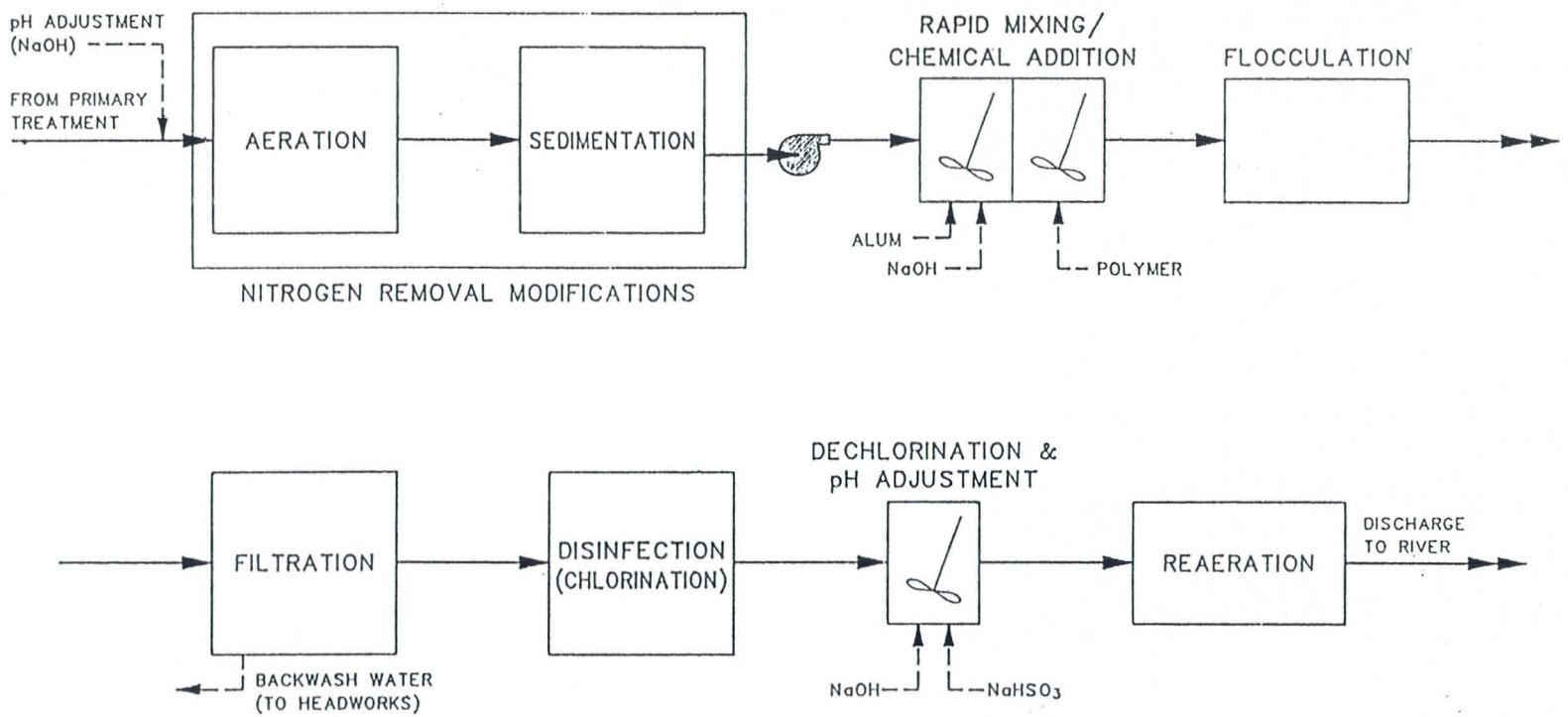
Item	Minimum[1]	Maximum
Capital Costs		
1. Nitrogen Removal Modifications (Opt.)	7.95	7.95
2. Effluent Equalization	7.62	7.62
3. Pump Station	5.60	5.60
4. Conveyance System	25.48	44.52
5. Percolation Site	19.82	83.30
6. Chlorination for Buckeye Irrigation Company	3.36	3.36
TOTAL[2]	69.83	152.35
ANNUAL[3]	7.11	15.52
Annual Operation and Maintenance Costs		
1. Power	2.61	2.61
2. Chemicals	0.22	0.22
3. Labor	2.71	2.84
4. Materials	0.09	0.12
TOTAL O&M COSTS	5.63	5.79
TOTAL ANNUAL COSTS	**12.74**	**21.31**

1. Minimum costs based on 700 acres required for percolation site maximum costs based on 2,400 acres required for percolation site.

2. Includes contingencies, engineering fees, administration.

3. Amortized over 20 years at 8 percent.

FIGURE 1

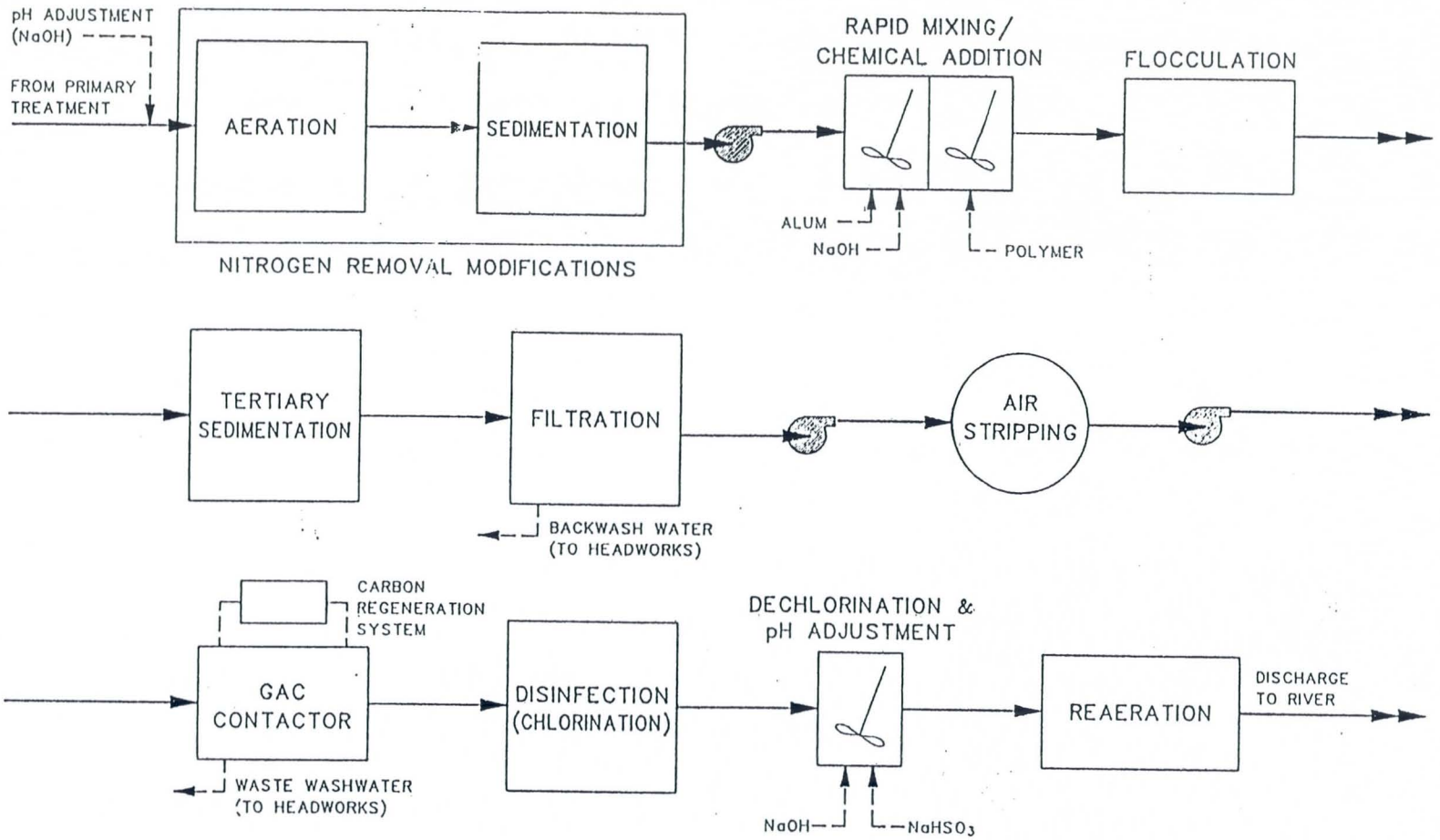


TREATMENT PROCESS SCHEMATIC
DRAFT NPDES PERMIT

GREELEY AND HANSEN

CITY OF PHOENIX
TOTAL EFFLUENT REUSE STUDY

FIGURE 2



TREATMENT PROCESS SCHEMATIC
PROPOSED NAVIGABLE WATER QUALITY STANDARDS

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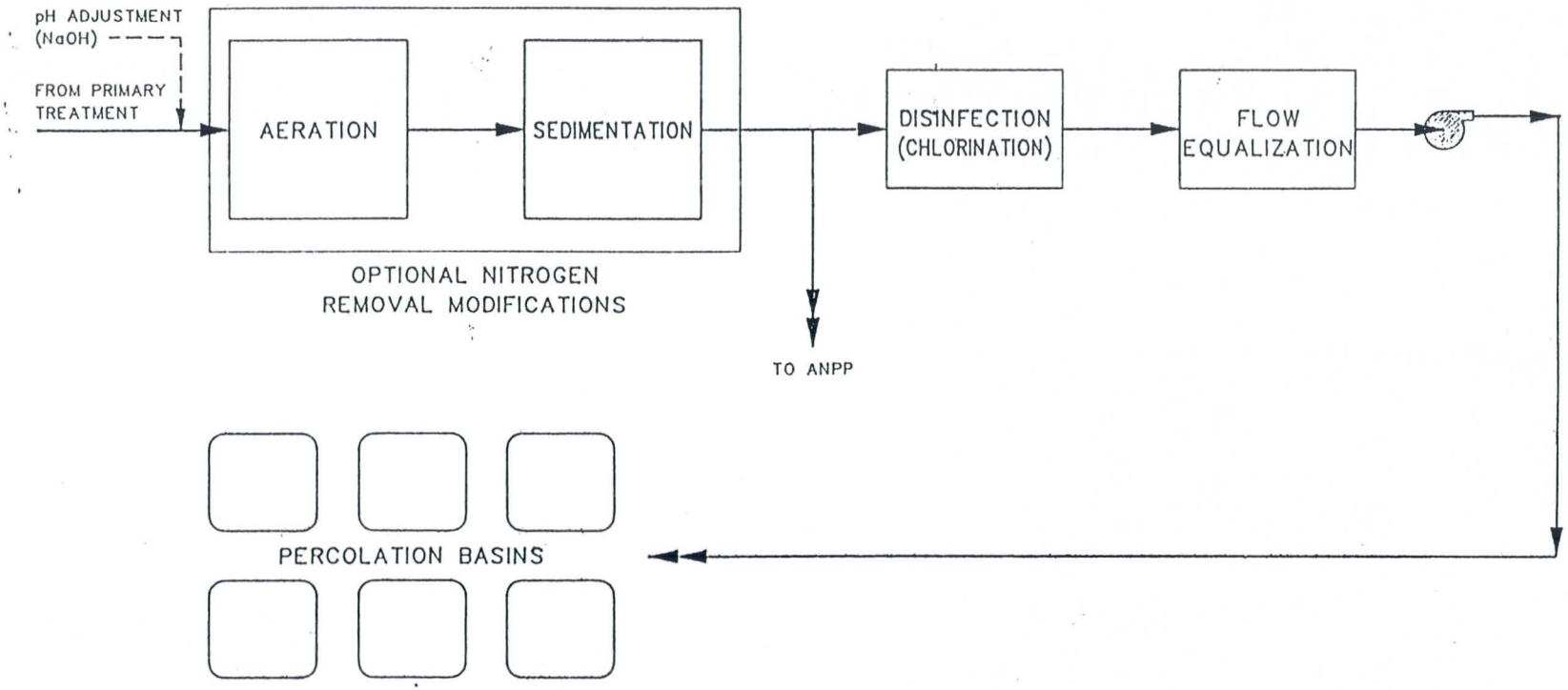
CITY OF PHOENIX
TOTAL EFFLUENT REUSE STUDY

FIGURE 3



TREATMENT PROCESS SCHEMATIC
TOTAL REUSE ALTERNATIVE

GREELEY AND HANSEN

CITY OF PHOENIX
TOTAL EFFLUENT REUSE STUDY

PANEL DISCUSSION
THE FUTURE of WATER REUSE in ARIZONA

Moderator:	*Karl Kohlhoff*	*City of Mesa*
	Bruce Johnson	*Tucson Water*
	Leonard Dueker	*City of Scottsdale*
	Grant Anderson	*City of Glendale*
	Herb Dishlip	*DWR*
	Sue Lofgren	*Concerned Citizen*

3:50 pm -- 4:50 pm

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Attendees Mailing List
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Gaylord, Karen	City of Tempe P. O. Box 5002 Tempe, AZ 85281	(602) 350-8227
Gerba, Dr. Charles	U of A Dept of Soil & Water Science Tucson, AZ 85721	
Gergely, Wendell	P.O. Box 31012 Phoenix, AZ 85046	(602) 971-3211
Gibbons, June	Bureau of Reclamation P. O. Box 9980 Phoenix, AZ 85068-0980	(602) 870-2136
Gibbs, Ivon	City of Peoria 8850 N. 79Th Ave. Peoria, Az 85345	(602) 412-7430
Giles, Dave	Glendale Water Production 4805 W. Cholla Glendale, AZ 85304	(602) 931-5470
Goddard, Jr., Sam	Goddard Law Firm 845 N. Third Ave. Phoenix, AZ 85003	
Gordillo, Veronica	University of Arizona 333 W. Roger Rd. Apt 12 Tucson, Az 85705	(602) 621-6910
Gorey, Tim	Salt River Project 1521 Project Drive, PAB-112 Phoenix, AZ 85281	(602) 236-2702

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Gorny, Donald	Mar-Wood, Inc. 8501 N. 75th Ave. Peoria, Az 85345	(602) 486-9445
Gritzuk, Mike	City of Phoenix 455 N. 5Th St. Phoenix, Az 85004	
Hains, Dorothy	ADEQ P. O. Box 600 Phoenix, Az 85001	(602) 207-4615
Hallin, Bruce	Salt River Project 1521 Project Drive, ISB-666 Tempe, AZ 85281	(602) 236-3212
Hallman, Norman	Town of Gilbert 525 N. Lindsay Rd. Gilbert, Az 85234	(602) 497-9191
Haney, William	City of Mesa P. O. Box 1466 Mesa, AZ 85211-1466	(602) 644-2480
Hargis, Howard	City of Tempe P. O. Box 5002 Tempe, AZ 85281	(602) 350-8200
Harrington, Richard	Pima Co WW 201 N Stone, 8th fl Tucson, Az 85701	(602) 740-6500
Hasan, Michaela	University of Arizona Building #90 Room 409 Tucson, Az 85721	(602) 621-6910

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Sorted by Last Name

Hastings, Lisa	ADEQ 3033 N. Central Phoenix, AZ 85012	(602) 207-4425
Hendricks, Paul	Phoenix Waste Water Trt 2301 W. Durango Phoenix, Az 85009	(602) 262-1857
Hildreth, Steven	Arizona State Land Dept 1616 W Adams St Phoenix, AZ 85007	(602) 542-2119
Hoffman, Byford (Biff)	Salt River Project P.O. Box 52025 Phoenix, AZ 85072-2025	(602) 236-5977
Houston, Sandra	Arizona State University Dept of Civil Engineering Tempe, AZ 85287-5306	(602) 965-3589
Huza, Brad	City of Prescott P.O. Box 2059 Prescott, Az 85302	(602) 445-3500
Ingram, Blaine	Blaine Ingram Inc 2020 E. Solar Dr. Phoenix, Az 85020	(602) 943-8832
Jeffries, Dick	Boyle Eng. Corp. 7600 N. 16Th St. #223 Phoenix, Az 85020	(602) 943-6800
Johnson, Bruce	Tucson Water P.O. Box 27210 COT Tucson, AZ 85726-7210	(602) 791-2689

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Johnson, Carol	City of Scottsdale 9388 E. San Salvador Scottsdale, Az 85258	(602) 391-5685
Johnson, Dana	University of Arizona Micro/Immuno Bldg #90 Tucson, Az 85721	(602) 621-6910
Johnson, Richard	John Carollo Engineers 3877 N. 7th St. Phoenix, Az 85014	(602) 263-9500
Karlson, Gary	DCD Company, Inc. 241 N. Roosevelt Ave. Chandler, Az 85226	(602) 833-8612
Kasem, Mike	Glendale Water Production 4805 W. Cholla Glendale, AZ 85304	(602) 931-5470
Kaylor, James	City of Glendale 6210 W. Myrtle Suite 112 Glendale, Az 85301	(602) 931-5561
King, Kirke	U.S. Fish & Wildlife Service 3616 W. Thomas Rd. Suite 6 Phoenix, AZ 85019	(602) 379-4720
Knickerbocker, Ken	Coe & Van Loo 4550 N. 12th St Phoenix, Az 85014	(602) 264-6831
Kohlhoff, Karl	City of Mesa 20 E. Main, Suite 570 Mesa, Az 85211-0000	

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Attendees Mailing List
Sorted by Last Name

Kulakowski, Lois	Southern Ariz Water Res Assoc 48 N. Tucson Blvd, Suite 106 Tucson, AZ 85716	(602) 881-3939
Lally, Michael	ASL Hydr. Environ Services 2701 N 16th St, Suite 106 Phoenix, AZ 85202	(602) 263-9522
Larson, Keith	City of Phoenix 455 N. 5th St. Phoenix, AZ 85004	(602) 495-3669
Larson, Scott	American Engineering Co. 21442 N. 20Th Ave. Phoenix, Az 85027	(602) 582-0260
Lenczewski, Melissa	University of Arizona Building 90 Room 409 Tucson, Az 85721	(602) 621-6910
Lindstrom, Shane	USDA Soil Conservation Service 220 N. 4th Street Buckeye, AZ 85326	(602) 386-4631
Linsky, Ron	National Water Research Inst. P.O. Box 20865, 10500 Ellis Av Fountain Valley CA 92728-0865	(714) 378-3278
Lluria, Maria delCarman	University of Arizona 215 E. Suffolk Tucson, AZ 85704	
Lluria, Mario	Salt River Project P.O. Box 52025 Phoenix, AZ 85072-2025	(602) 236-5520

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Sorted by Last Name

Lobosco, Emil	Glendale Water Production 4805 W. Cholla Glendale, AZ 85304	(602) 931-5470
Lofgren, Sue	The FORUM 2411 S. Newberry Road Tempe, Az 85282	
Lopez, Ronny	City of Mesa P. O. Box 1466 Mesa, AZ 85211-1466	(602) 644-2483
Lynch, Robert	Irrig & Elec Dist Assoc of Az 2001 N. #rd Street, Suite 204 Phoenix, AZ 85004-1472	(602) 254-5908
Lynn, Pat	P L Communication Srvcs 9617 S. 45th Place Phoenix, Az 85004	(602) 893-1006
Ma, JuFang	University of Arizona Building #90 Room 409 Tucson, Az 85721	(602) 621-6910
MacTough, Sandy	AZ Dept of Water Resources 16612 S. 14th St Phoenix, AZ 85044	(602) 542-1512
Maseeh, George	Malcolm Pirnie, Inc. 450 W. Paseo Redondo, Ste 206 Tucson, Az 85701	(602) 629-9982
Matt, Denise	City of Phoenix 2007 N. 73rd Ave Phoenix, AZ 85035	(602) 849-1073

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Attendees Mailing List
Sorted by Last Name

McAllister, Jim	City of Glendale 5850 W. Glendale Ave Glendale, AZ 85301	(602) 435-4249
McCain, Bob	AMWUA 4041 N. Central Ave., Ste. 900 Phoenix, AZ 85012	(602) 248-8482
Meyer, Harry	City of Tempe P. O. Box 5002 Tempe, AZ 85281	(602) 350-2623
Miley, Terry	Tucson Water P.O. Box 27210 COT Tucson, AZ 85726-7210	(602) 791-2689
Miller, Beth	City of Mesa 640 E. Sixth Street Mesa, AZ 85211-1466	(602) 644-3334
Miller, Janene	Salt River Project P.O. Box 52025 Phoenix, AZ 85072-2025	(602) 236-5745
Miller, Paul	Water Masters Inc P.O. Box 47146 Phoenix, Az 85068	(602) 944-2811
Miller, Ron	City of Scottsdale 9388 E. San Salvador Scottsdale, AZ 85258	(602) 391-5685
Mitchell, Jim	City of Avondale 525 N. Central Avenue Avondale, AZ 85323	(602) 932-1909

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Sorted by Last Name

Moore, Catesby	Maricopa County Flood Control 2801 W. Durango Phoenix, AZ 85009	(602) 506-1501
Moorhead, Brian	Salt River Project 1521 Project Drive, PAB-102 Tempe, AZ 85281	(602) 236-5304
Nordvold, Norris	City of Phoenix 251 W. Washington, 10th. Floor Phoenix, AZ 85003	(602) 256-4257
Panetta, Chris	City of Peoria 8041 W. Monroe St Peoria, Az 85345	(602) 412-7433
Pawlowski, Steve	ADEQ 3033 N. Central, Room 825 Phoenix, AZ 85012	(602) 207-2227
Popoff, Mike	Environmental Utilities Serv 12728 W. Desert Cove El Mirage, AZ 85335	(602) 582-8560
Power, John	Maricopa Cnty EQCSA 2406 S. 24 St, Ste E 204 Phoenix, AZ 85034	(602) 506-6616
Prevatt, Frank	U of A 1325 S. Beaver Dr. Tucson, AZ 85713	
Putman, Frank	AZ Dept of Water Resources 15 S. 15th Ave. Phoenix, AZ 85004	(602) 542-1586

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Puzauskas, Jr, John	John Carollo Engineers 3877 N. 7Th St. #400 Phoenix, Az 85014	(602) 263-9500
Quaas, Lee	City of Tempe P. O. Box 5002 Tempe, AZ 85281	(602) 350-8200
Quanrud, David	University of Arizona 875 E. Alturas Street Tucson, AZ 85719	(602) 791-2742
Randall, Rich	CH2MHILL 1620 W. Fountainhead Pkwy #550 Tempe, AZ 85282	(602) 966-8188
Reed, Richard	Blaine Ingram Inc 4021 N. 31st Ave, PO Box 27296 Phoenix, Az 85061	(602) 650-1557
Reynolds, Carroll	City of Chandler 249 E. Chicago St. Chandler, Az 85225	(602) 786-2759
Richardson, Andy	Greeley & Hansen 426 N. 44th Street Phoenix, AZ 85008	(602) 275-5595
Rigby, Dr. Martin	Orange Cty Water District 10500 Ellis Ave, PO Box 8300 Fountain Valley CA 92728-8300	(714) 963-5661
Rivera, Marco	City of Nogales 777 N. Grand Avenue Nogales, AZ 85621	(602) 287-6571

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Roth, Glen	Coe & Van Loo 4550 N. 12th St Phoenix, Az 85014	(602) 264-6831
Rule, Dennis	Tucson Water P.O. Box 27210 COT Tucson, AZ 85726-7210	(602) 791-2689
Ryckman-Siegwarth, Jane	Camp Dresser & McKee 3200 E. Camelback, Suite 110 Phoenix, AZ 85019	(602) 956-0666
Sands, Tom	Salt River Project 1521 Project Drive, PAB-102 Tempe, AZ 85281	(602) 236-2371
Sefton, Frank	Glendale Water Production 4805 W. Cholla Glendale, AZ 85304	(602) 931-5470
Self, Oralynn	Greeley & Hansen 426 N. 44Th St. #400 Phoenix, Az 85008	(602) 275-5595
Shafer, Bill	ADEQ 3033 N. Central Ave. Phoenix, AZ 85012	(602) 207-2300
Sheikh, Dr. Bahman	L.A. Office of Water Reclamatn RM 366 City Hall, 200 N Spring Los Angeles, CA 90012	(213) 237-0887
Shirley, Dennis	Salt River Project 1521 Project Drive, PAB-352 Phoenix, AZ 85281	(602) 236-2685

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Sorted by Last Name

Stark, Glenn	Gila River Indian Community P. O. Box 370 Sacaton, AZ 85247	(602) 562-3203
Stephenson, Gordon	ASL Hydr. Environ Services 2701 N 16th St, Suite 106 Phoenix, AZ 85202	(602) 263-9522
Stinnett, Robin	AMWUA 4041 N. Central Ave., Ste. 900 Phoenix, AZ 85012	(602) 248-8482
Strand, Charles	Town of Gilbert 1025 S. Gilbert Rd Gilbert, Az 85234	(602) 892-0800
Tallent, Ronald	Az Dept of Transportation 206 S. 17Th Ave. #176A Phoenix, Az 85007	(602) 255-7388
Taylor, Clifton	Az Dept of Transportation 206 S. 17Th Ave. #176A Phoenix, Az 85007	(602) 255-7388
Taylor, Ron	Salt River Project P.O. Box 52025 Phoenix, AZ 85072-2025	(602) 236-6557
Testa, Ann	City of Mesa 640 E. Sixth Street Mesa, AZ 85211-1466	(602) 644-3058
Thomas, Doug	City of Lake Havasu 1150 McCulloch Blvd. Lake Havasu Cit AZ 86403	(602) 855-3999

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Attendees Mailing List
Sorted by Last Name

Thomas, Harold	Salt River Project P.O. Box 52025 Phoenix, AZ 85072-2025	(602) 236-4359
Thompson, Ken	Irvine Irrigation District 15600 Sand Cnyn Av,PO Box 6025 Irvine, CA 92716-6025	(714) 453-5620
Thompson, Oren	Salt River Project P.O. Box 52025 Phoenix, AZ 85072-2025	(602) 236-3455
Thurston, Lucia	Pima County Wastewater Mgmt 201 N. Stone Ave, 8th fl Tucson, AZ 85701	(602) 740-6549
Vahouick, Ted	N. Gila Cnty Sani Dist P.O. Box 591 Payson, Az 85547	(602) 474-5257
Wahlstrom, Linda	Glendale Water Production 4805 W. Cholla Glendale, AZ 85304	(602) 931-5470
Ward, Nancy	Tucson Water P.O. Box 27210 COT Tucson, AZ 85726-7210	(602) 791-2689
Watt, Pam	University of Arizona Building #90 Room 409 Tucson, Az 85721	(602) 621-6910
Wheeler, William	CAPA 6317 N. 14th St. Phoenix, AZ 85014	

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Wilson, William	Water Masters Inc P.O. Box 47146 Phoenix, Az 85068	(602) 944-2811
Wolan, John	Pinetop-Lksd Sani Dist 2600 W. Alisa Lane Lakeside, Az 85929	(602) 368-5370
Wonderley, Wendy	Bookman-Edmonston Engineering 340 E. Palm Lane Suite 250 Phoenix, AZ 85004	(602) 956-4747

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Gergely, Wendell	P.O. Box 31012 Phoenix, AZ 85046	(602) 971-3211
Larson, Scott	American Engineering Co. 21442 N. 20Th Ave. Phoenix, Az 85027	(602) 582-0260
Francom, Stan	Arizona Sierra Utility Co 459 N. Gilbert Rd. Ste A198 Gilbert, AZ 85234	(602) 899-5255
Hildreth, Steven	Arizona State Land Dept 1616 W Adams St Phoenix, AZ 85007	(602) 542-2119
Houston, Sandra	Arizona State University Dept of Civil Engineering Tempe, AZ 85287-5306	(602) 965-3589
Tallent, Ronald	Az Dept of Transportation 206 S. 17Th Ave. #176A Phoenix, Az 85007	(602) 255-7388
Taylor, Clifton	Az Dept of Transportation 206 S. 17Th Ave. #176A Phoenix, Az 85007	(602) 255-7388
Bell, Donald	ADEQ P.O. Box 600 Phoenix, Az 85001	(602) 207-4613
Hains, Dorothy	ADEQ P. O. Box 600 Phoenix, Az 85001	(602) 207-4615

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Fox, Gordon	ADEQ 2501 N. 4th St. #14 Flagstaff, AZ 86004	(602) 779-0313
Breckenridge, Jerry	ADEQ 2501 N. 4th St. #14 Flagstaff, AZ 86004	(602) 779-0313
Shafer, Bill	ADEQ 3033 N. Central Ave. Phoenix, AZ 85012	(602) 207-2300
Pawlowski, Steve	ADEQ 3033 N. Central, Room 825 Phoenix, AZ 85012	(602) 207-2227
Chien, Josephine	ADEQ 3033 N. Central Phoenix, AZ 85012	(602) 207-4422
Hastings, Lisa	ADEQ 3033 N. Central Phoenix, AZ 85012	(602) 207-4425
Stinnett, Robin	AMWUA 4041 N. Central Ave., Ste. 900 Phoenix, AZ 85012	(602) 248-8482
McCain, Bob	AMWUA 4041 N. Central Ave., Ste. 900 Phoenix, AZ 85012	(602) 248-8482
Stephenson, Gordon	ASL Hydr. Environ Services 2701 N 16th St, Suite 106 Phoenix, AZ 85202	(602) 263-9522

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Lally, Michael	ASL Hydr. Environ Services 2701 N 16th St, Suite 106 Phoenix, AZ 85202	(602) 263-9522
Putman, Frank	AZ Dept of Water Resources 15 S. 15th Ave. Phoenix, AZ 85004	(602) 542-1586
MacTough, Sandy	AZ Dept of Water Resources 16612 S. 14th St Phoenix, AZ 85044	(602) 542-1512
Brown, Steven	AZ Dept of Water Resources 1451 E. Piute Phoenix, AZ 85024	(602) 542-1512
Dishlip, Herb	AZ Dept of Water Resources 15 S. 15th Avenue Phoenix, Az 85007	
Beatty, Joseph	B-T Consulting Eng Serv 1475 Verde Vly School Rd. Sedona, Az 86336	(602) 284-0124
Ingram, Blaine	Blaine Ingram Inc 2020 E. Solar Dr. Phoenix, Az 85020	(602) 943-8832
Reed, Richard	Blaine Ingram Inc 4021 N. 31st Ave, PO Box 27296 Phoenix, Az 85061	(602) 650-1557
Wonderley, Wendy	Bookman-Edmonston Engineering 340 E. Palm Lane Suite 250 Phoenix, AZ 85004	(602) 956-4747

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Jeffries, Dick	Boyle Eng. Corp. 7600 N. 16Th St. #223 Phoenix, Az 85020	(602) 943-6800
Edmondson, Samuel	Brown & Caldwell 345 E. Palm Ln., Suite 200 Phoenix, AZ 85004	
Colvin, Gary	Buckeye Irrigation District P. O. Box 726 Buckeye, AZ 85326	(602) 386-2196
Gibbons, June	Bureau of Reclamation P. O. Box 9980 Phoenix, AZ 85068-0980	(602) 870-2136
Fulton, Jim	Camp Dresser & McKee 3200 E Camelback, Suite 110 Phoenix, AZ 85018	(602) 956-0666
Ryckman-Siegwarth, Jane	Camp Dresser & McKee 3200 E. Camelback, Suite 110 Phoenix, AZ 85019	(602) 956-0666
Fleury, Mike	Camp Dresser & McKee 110 S. Church Avenue, Ste 190 Tucson, AZ 85701	(602) 792-3573
Crook, Dr. James	Camp Dresser & McKee 10 Cambridge Center Cambridge, MA 02142	(617)252-8497
Clark, Scott	Citizens Utilities 15626 N. Del Webb Sun City, AZ 85351	(602) 876-4035

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Mitchell, Jim	City of Avondale 525 N. Central Avenue Avondale, AZ 85323	(602) 932-1909
Bates, Bill	City of Avondale 525 N. Central Avenue Avondale, AZ 85323	(602) 932-1909
Anglin, Jerry	City of Casa Grande 300 E. 4Th St. Casa Grande, Az 85222	(602) 836-5090
Reynolds, Carroll	City of Chandler 249 E. Chicago St. Chandler, Az 85225	(602) 786-2759
Alberhasky, Joellen	City of Glendale 6210 W. Myrtle Suite 112 Glendale, Az 85301	(602) 931-5561
Compton, Glenn	City of Glendale 5850 W. Glendale Ave Glendale, Az 85301	(602) 435-4152
Kaylor, James	City of Glendale 6210 W. Myrtle Suite 112 Glendale, Az 85301	(602) 931-5561
Fletcher, Russell	City of Glendale 5850 W. Glendale Ave Glendale, Az 85301	(602) 435-4152
Anderson, Grant	City of Glendale 5850 West Glendale Ave. Glendale, AZ 85301	(602) 435-4152

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McAllister, Jim	City of Glendale 5850 W. Glendale Ave Glendale, AZ 85301	(602) 435-4249
Thomas, Doug	City of Lake Havasu 1150 McCulloch Blvd. Lake Havasu Cit AZ 86403	(602) 855-3999
Haney, William	City of Mesa P. O. Box 1466 Mesa, AZ 85211-1466	(602) 644-2480
Evans, Wayne	City of Mesa P. O. Box 1466 Mesa, AZ 85211-1466	(602) 633-3229
Kohlhoff, Karl	City of Mesa 20 E. Main, Suite 570 Mesa, Az 85211-0000	
Testa, Ann	City of Mesa 640 E. Sixth Street Mesa, AZ 85211-1466	(602) 644-3058
Miller, Beth	City of Mesa 640 E. Sixth Street Mesa, AZ 85211-1466	(602) 644-3334
Lopez, Ronny	City of Mesa P. O. Box 1466 Mesa, AZ 85211-1466	(602) 644-2483
Bradford, Dick	City of Mesa P. O. Box 1466 Mesa, AZ 85211-1466	(602) 644-2131

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Colbath, Russell	City of Mesa 4048 E. Pueblo Mesa, AZ 85206	(602) 644-2263
Rivera, Marco	City of Nogales 777 N. Grand Avenue Nogales, AZ 85621	(602) 287-6571
Backus, Ron	City of Peoria 8041 W. Monroe St. Peoria, AZ 85345	(602) 412-7433
Gibbs, Ivon	City of Peoria 8850 N. 79Th Ave. Peoria, Az 85345	(602) 412-7430
Panetta, Chris	City of Peoria 8041 W. Monroe St Peoria, Az 85345	(602) 412-7433
Essex, Max	City of Phoenix R.R. 1 Box 470 Scottsdale, Az 85264	(602) 945-0562
Gritzuk, Mike	City of Phoenix 455 N. 5Th St. Phoenix, Az 85004	
Larson, Keith	City of Phoenix 455 N. 5th St. Phoenix, AZ 85004	(602) 495-3669
Nordvold, Norris	City of Phoenix 251 W. Washington, 10th. Floor Phoenix, AZ 85003	(602) 256-4257

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Doyle, Marsha	City of Phoenix 19420 N. 13th Ave Phoenix, AZ 85027	(602) 495-7705
Chase, William	City of Phoenix 251 W. Washington St Phoenix, AZ 85003	(602) 256-3248
Bienz, Edna	City of Phoenix 3030 W. Dunlap Phoenix, Az 85051	(602) 262-6161
Matt, Denise	City of Phoenix 2007 N. 73rd Ave Phoenix, AZ 85035	(602) 849-1073
Huza, Brad	City of Prescott P.O. Box 2059 Prescott, Az 85302	(602) 445-3500
Craig, Marty	City of Scottsdale 9388 E. San Salvador Scottsdale, Az 85258	(602) 391-5685
Johnson, Carol	City of Scottsdale 9388 E. San Salvador Scottsdale, Az 85258	(602) 391-5685
Miller, Ron	City of Scottsdale 9388 E. San Salvador Scottsdale, AZ 85258	(602) 391-5685
Dueker, Leonard	City of Scottsdale 9388 E. San Salvador Dr. Scottsdale, Az 85258	

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Meyer, Harry	City of Tempe P. O. Box 5002 Tempe, AZ 85281	(602) 350-2623
Ankeny, Thomas	City of Tempe P. O. Box 5002 Tempe, AZ 85281	(602) 350-8200
Quaas, Lee	City of Tempe P. O. Box 5002 Tempe, AZ 85281	(602) 350-8200
Hargis, Howard	City of Tempe P. O. Box 5002 Tempe, AZ 85281	(602) 350-8200
Gaylord, Karen	City of Tempe P. O. Box 5002 Tempe, AZ 85281	(602) 350-8227
Knickerbocker, Ken	Coe & Van Loo 4550 N. 12th St Phoenix, Az 85014	(602) 264-6831
Roth, Glen	Coe & Van Loo 4550 N. 12th St Phoenix, Az 85014	(602) 264-6831
Wheeler, William	CAPA 6317 N. 14th St. Phoenix, AZ 85014	
Randall, Rich	CH2MHILL 1620 W. Fountainhead Pkwy #550 Tempe, AZ 85282	(602) 966-8188

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DeGrande, Vic	CH2MHILL 1620 W. Fountainhead Pkwy #550 Tempe, AZ 85282	(602) 966-8188
Condit, Robert	CMID-Cortaro-Marana Irrig Dist 13864 N. Sandario Road Marana, AZ 85653	(602) 682-3233
Devkota, Laxman Mani	Damon S. Williams Assoc 645 E. Missouri Ave #270 Phoenix, Az 85012	(602) 265-5400
Conroy, Aimee	Damon S. Williams Assoc 645 E. Missouri Ave #270 Phoenix, Az 85012	(602) 265-5400
Darmiento, Frank	Darmiento Environmental Mgmt P.O. Box 13623 Scottsdale, AZ 85267	(602) 948-7688
Daugherty, Kevin	Drywell Doctors P. O. Box 37273 Phoenix, AZ 85069	(602) 934-5935
Karlson, Gary	DCD Company, Inc. 241 N. Roosevelt Ave. Chandler, Az 85226	(602) 833-8612
Clune, James	E.O.S. P.O. Box 12725 Scottsdale, Az 85267	(602) 585-0890
Buranich, Lou	Environmental Utilities Serv 19105 N. 75th Dr Glendale, AZ 85308	(602) 582-8560

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Popoff, Mike	Environmental Utilities Serv 12728 W. Desert Cove El Mirage, AZ 85335	(602) 582-8560
Cannon, George	General Environmental Systems 4633 E Broadway Ste 105 Tucson, AZ 85711	
Briggs, Phillip	Geraghty & Miller Inc. 8222 S. 48th St Phoenix, AZ 85044	(602) 438-0883
Stark, Glenn	Gila River Indian Community P. O. Box 370 Sacaton, AZ 85247	(602) 562-3203
Blackwater, Errol	Gila River Indian Community P. O. Box 370 Sacaton, AZ 85247	(602) 562-3203
Wahlstrom, Linda	Glendale Water Production 4805 W. Cholla Glendale, AZ 85304	(602) 931-5470
Sefton, Frank	Glendale Water Production 4805 W. Cholla Glendale, AZ 85304	(602) 931-5470
Lobosco, Emil	Glendale Water Production 4805 W. Cholla Glendale, AZ 85304	(602) 931-5470
Barton, Rick	Glendale Water Production 4805 W. Cholla Glendale, AZ 85304	(602) 931-5470

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Kasem, Mike	Glendale Water Production 4805 W. Cholla Glendale, AZ 85304	(602) 931-5470
Giles, Dave	Glendale Water Production 4805 W. Cholla Glendale, AZ 85304	(602) 931-5470
Goddard, Jr., Sam	Goddard Law Firm 845 N. Third Ave. Phoenix, AZ 85003	
Self, Oralynn	Greeley & Hansen 426 N. 44Th St. #400 Phoenix, Az 85008	(602) 275-5595
Ambrose, Wallace	Greeley & Hansen 426 N. 44Th St. #400 Phoenix, Az 85008	(602) 275-5595
Richardson, Andy	Greeley & Hansen 426 N. 44th Street Phoenix, AZ 85008	(602) 275-5595
Lynch, Robert	Irrig & Elec Dist Assoc of Az 2001 N. #rd Street, Suite 204 Phoenix, AZ 85004-1472	(602) 254-5908
Thompson, Ken	Irvine Irrigation District 15600 Sand Cnyn Av,PO Box 6025 Irvine, CA 92716-6025	(714)453-5620
Duren, Fred	James Montgomery 6245 N 24th Parkway, Suite 208 Phoenix, AZ 85016	(602) 954-6781

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OWR NEWS

SPECIAL Water Environment Federation SUPPLEMENT

Formerly Water Pollution Control Federation

Volume 3, Issue 3 September 1992

WATER RECLAMATION AND REUSE: WHAT YOU NEED TO KNOW

This supplement is a draft of an educational tool being prepared by the Water Reuse Committee of the Water Environment Federation. This draft is being distributed for comment at WEF's national conference in New Orleans. For our OWR NEWS readers who wish to comment on any aspect of this supplement, please send your remarks to Mr. Paul Findley at the City of San Diego Clean Water Program, 401 B Street, Suite 710, San Diego, CA 92101.

WHAT IS THE PROBLEM?

For many communities, traditional natural supplies of freshwater -- streams, rivers, lakes, or groundwater aquifers -- are being diminished and degraded as they are used for municipal, industrial, and agricultural uses, and for waste disposal. In some regions, water is so scarce that aqueduct systems hundreds of miles long and dams costing billions of dollars have been built just to keep pace with growing demand for water. At the same time, increasingly stringent environmental regulations have led to construction of equally costly public works systems for the treatment and disposal of municipal and industrial wastewater.

CAN RECLAMATION SOLVE THE PROBLEM?

It can help. Water reclamation is the treatment and management of wastewater to produce water suitable for reuse. It can help resolve the water supply problem by reducing the amount of freshwater required. Reclaimed water can replace potable water for non-potable uses, thus reserving the best and purest sources of water for the highest use -- public drinking water. It can reduce the amount of wastewater discharged to streams, rivers, lakes, and oceans. In fact, water reclamation is based on the premise that treated wastewater is too valuable to "throw away."

HOW IS RECLAIMED WATER PRODUCED?

The first step in producing reclaimed water is to find an adequate supply of reclaimable wastewater. All wastewater is not created equal. Wastewater from residential areas presents different characteristics than from industrial areas. Wastewater in sewers located near the ocean can have much higher salt content than wastewater from inland areas. Since high levels of dissolved minerals are undesirable to reclaimed water users, and are also difficult and expensive to remove in the treatment process, it is usually beneficial to find wastewater with low mineral content and to protect that wastewater from being contaminated by discharges of brine or other undesirable wastewater streams.

At the water reclamation plant, wastewater is subjected to primary and secondary treatment (always) and tertiary treatment (usually). In primary treatment, large inorganic and organic materials are separated from the wastewater by physical processes such as screening and sedimentation. Approximately one-half of the suspended solids are removed in the primary treatment step.

The secondary treatment step is largely a biological process. Air is supplied to stimulate the growth of bacteria and other organisms which consume most of the remaining waste materials. The organisms and solids can then be separated from the water by physi-

cal processes. This step removes 85 to 90 percent of organic materials and solids.

After secondary treatment, the type of tertiary treatment required depends on state and local regulations. Chemically assisted filtration of the water through beds of sand or other granular media is usually necessary, followed by disinfection using chlorine, ozone, or ultraviolet light, to kill any remaining harmful bacteria. Other processes may be added, including chemical coagulation, flocculation and sedimentation; carbon adsorption; and reverse osmosis or ion exchange.

HOW IS RECLAIMED WATER DISTRIBUTED?

In many cases, reclaimed water is delivered directly to users via a distribution system -- consisting of pump stations, pipelines, and storage reservoirs -- that is completely separate from the potable water distribution system. This separate distribution system can be the largest cost component of a water reclamation and reuse program. However, several other conveyance and distribution methods are also used. One method gaining popularity is to use reclaimed water to "recharge" groundwater basins. The reclaimed water then mixes with naturally occurring groundwater and is eventually pumped out and used at wells which can be miles away from the recharge site. Reclaimed water is sometimes discharged to naturally occurring surface water courses. Downstream users divert the water for use.

HOW IS RECLAIMED WATER USED?

In 1932, in the first project of its kind in the United States, San Francisco began using secondary-treated reclaimed water to irrigate Golden Gate Park. Since then, water reclamation has been applied in areas where dependable water supplies are scarce, where reuse markets are attainable, where wastewater disposal needs to be significantly reduced, and where energy and environmental considerations make reclamation a feasible option. Today, reclaimed water is used throughout the United States for a variety of purposes including landscape and agricultural irrigation, industrial and commercial uses, groundwater recharge, recreational and environmental uses, and nonpotable urban uses. Pioneering work has even been accomplished showing how reclaimed water can be used indirectly or directly as part of the potable water supply.

Irrigation

Agricultural and landscape irrigation are very common and successful uses of reclaimed water. To date, agricultural irrigation has been the most common type of reuse, with hundreds of crops, from alfalfa to zucchini, being successfully irrigated. Golf course irrigation is increasing partly because of the reliability of supply in times of drought. Other common landscape applications include parks, cemeteries, freeway medians, school grounds, community greenbelts, commercial and industrial park grounds, and athletic fields. Some communities are successfully operating reclaimed water systems that furnish reclaimed water to private residences.

Pipe laying in residential area for reclaimed water service.

Irrigation users are usually concerned about water quality, particularly the effect of salts and other trace constituents in reclaimed water on plants. Agricultural users must be assured that reclaimed water won't adversely affect crop yield or public accep-

WR NEWS

Office of Water Reclamation, City of Los Angeles

Volume 3, Issue 3 September 1992

High Cost of New Water Makes Recycling A Bargain

by Virginia Grebbien
Asst. General Manager
West Basin MWD

Recycling water is becoming increasingly important. In Southern California the supply of potable water is limited and we rely to a great extent on imported water. Existing sources of imported water are becoming increasingly unreliable and development of major new sources of imported water is unlikely. And despite strong water conservation efforts, the demand for water is expected to increase significantly over the next twenty years. In order to meet future demands for water, Southern California must become more self-sufficient.

Recycled water can be used for all types of greenbelt irrigation and numerous other non-potable uses. Many water agencies have found that large industrial users are concerned about the reliability of imported water supplies and are eager to convert to recycled water because of its dependability.

The Metropolitan Water District, which wholesales water to Southern California, has supported wa-

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New Water Rate Structure Based on Cost of Reuse

by Dorothy Green
DWP Commissioner

The Mayor's Blue Ribbon Committee appointed to develop a new water rate structure for the City of Los Angeles has developed a rate structure based on the cost of delivering reclaimed water.

The committee was charged with developing rates that would be equitable, encourage conservation, not penalize those who conserve, and protect businesses and jobs.

The Committee responded by adopting an approach to water rates that has been in effect for electrical power rates for many years and has found general acceptance within the power industry, but is new to the water industry. This approach is called marginal cost pricing.

Marginal cost pricing requires that the cost of water to the public be based on the cost of the next most secure source of water available to the city in order to meet the needs of its growing population. This next most secure source of supply is recycled water.

However, if all water sold in the city was sold at this price, we would collect more money than is needed to meet the needs of the Department of Water and Power to maintain and operate the water system and guarantee the best water quality possible.

Therefore, the Committee proposed the adoption of a two tier system of pricing: a low block rate based on the costs of maintaining the system, and a high block rate based on the marginal cost of extending the system in order to deliver reclaimed water to customers who can put it to beneficial use.

To encourage conservation, all fixed charges would be eliminated and all revenue for DWP would be based on water actually used. For home owners, the break point between the low and high block rates was set at a level that would not penalize those who conserve, but would encourage those who use the most, more than 175% of

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* Lake Balboa Opening!
* Recycling At Hyperion
* Potable Reuse
* County Will Double Reclamation In 5 Yrs.

Director's Letter

Water Reuse Has Come A Long Way

by Bahman Sheikh, Ph.D., P.E.

The City of Los Angeles can now boast an aggressive water reclamation program which includes three projects in operation, two in detailed design, several under planning and many in the conceptual state. What is even more profoundly important is the financial commitment to water recycling coming about in the proposed water rate structure. The articles in the last issue by DWP Commissioner Mary Nichols, and the Mayor's Blue-Ribbon Committee Chair W. Anthony Willoughby, and in this issue by DWP Commissioner Dorothy Green clearly indicate the political determination of the City to tap into this very logical resource now.

The economics of water reuse -- for too long clouded by the various subsidies favoring import of fresh water -- are now emerging with bright colors. As Federal and State subsidies disappear, the real cost of developing the next source of water is having a sobering effect. The handwriting is on the wall! Fortunately, it is being read and understood, not only in this, the second largest city in the United States, but also in other parched areas of the state and the rest of the country.

We have come a long way, indeed, but we have a longer way yet to go, requiring continued leadership in the City and throughout the state.

Red Tape Clogs Water Garden Project

A four-year regulatory odyssey finally may be drawing to a close for developers of a Santa Monica office park seeking to use recycled water in decorative fountains and for landscape irrigation. After many meetings with state officials, two engineering reports, an environmental impact report and a report of findings of virus inactivation studies, the developers have yet to receive the go-ahead to use reclaimed water at the project. Since delivering the last document to officials over a year ago, the City of Santa Monica has received no official communication regarding the status of the state's evaluation of the system.

The Water Garden, a recently constructed 650,000 square-foot office park, has an on-site water reclamation plant that began operating April 1, 1992. Since water quality testing began in June, the plant has consistently met California's stringent Title 22 standards for reclaimed water.

The Water Garden's decorative fountains

Before beginning to use the reclaimed water, the City of Santa Monica and the office park owners need a discharge permit from the Regional Water Quality Control Board. That permit is on hold pending an evaluation by the state Department of Health Services. Meanwhile, 20,000 gallons of reclaimed water per day are being wasted.

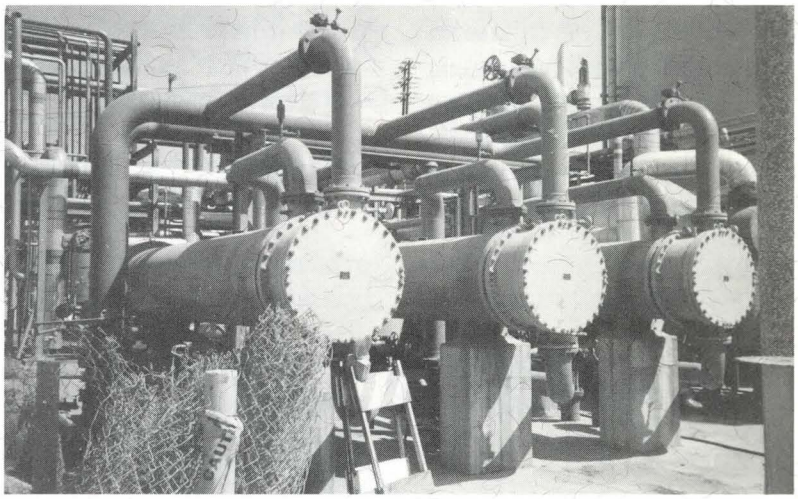
Relief may be in sight. The Department of Health Services has scheduled a meeting for the end of September to discuss some of the results of their evaluation. Let's hope for an expeditious end to the regulatory process so that this valuable resource can be utilized.

Hyperion's HERS To Boost Use of Reclaimed Water

Los Angeles' Hyperion Wastewater Treatment Plant is a substantial user of reclaimed water. The plant uses secondary-treated reclaimed water for cooling, irrigation and condensation. Now, with an expansion of the Hyperion Energy Recovery System (HERS), the plant will use even more reclaimed water.

Most of the water recycled at Hyperion is done so in connection with the HERS project. HERS produces energy by burning two by-products of wastewater treatment, digester gas and sludge. Thus, it produces energy, lowers the release of gas to the atmosphere and reduces the need for alternative sludge disposal. The project is nationally recognized and creates revenue for the City through the sale of electricity.

With the new expansion, HERS will nearly double its output by 1998. The use of reclaimed water will grow accordingly. The HERS project demonstrates once again that many products that were once wasted, such as digester gas or treated wastewater, are actually resources that can be used beneficially.



Recycled water in use at the Hyperion Energy Recovery System

Initial Headworks Data Confirm Safety of Groundwater Recharge

by Ali A. Karimi, Ph.D., P.E.

The initial results of a major study of the use of reclaimed water to supplement groundwater supplies confirm that the practice is safe. Water taken from an aquifer that had been recharged with reclaimed water consistently met California's strict drinking water quality standards.

Since June 1991, the Headworks Reclaimed Water Pilot Recharge Study team has allowed reclaimed water to flow into the San Fernando Valley Groundwater Basin through a spreading ground. They then extract the water at a pumping well approximately 700 feet downgradient. In addition, four monitoring wells are used to chart the movement and quality of the groundwater in surrounding areas. The study will continue through June 1993.

Analytical results from the first year of the pilot study show that the extracted water complied with all drinking water standards. Complete removal of coliform bacteria from the extracted water was verified. The organic content of the water represented by such parameters as Biochemical Oxygen Demand (BOD) and Total Organic Carbon (TOC) were reduced by 93 percent and 86 percent respectively. Their average concentrations in the extracted water were 1.0 mg/L and 1.6 mg/L respectively.* The study monitors 184 water quality constituents.

*There are no BOD or TOC standards for drinking water. However, both are important indicators of water quality.

Dr. Ali A. Karimi is a Water Quality Planning Engineer with the DWP, and the Principal Investigator for the Headworks Reclaimed Water Pilot Recharge Study.

COST

continued from Page 1

ter reclamation through its Local Projects Program (LPP). Metropolitan provides a rebate of $154 per acre-foot (AF) of reclaimed water produced under the LPP.

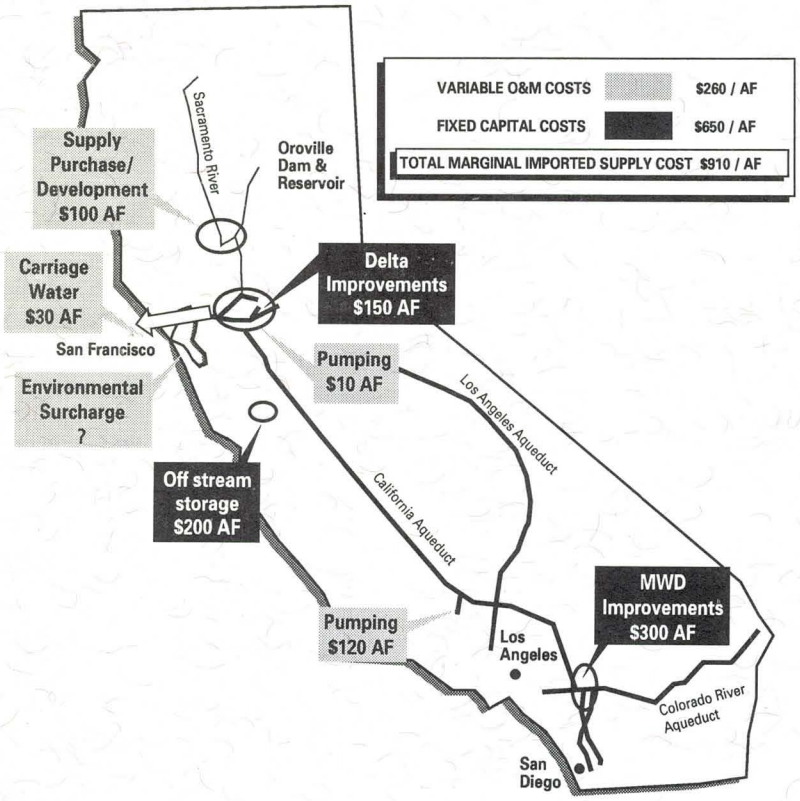
To qualify for the LPP rebate, a program must meet two basic criteria: it must replace or offset a demand for imported water, and it must need financial assistance (it must cost more than Metropolitan's treated, non-interruptible water rate.) Metropolitan determines financial need by comparing a facility's projected costs to their projected water rates. A program will receive the LPP rebate until its projected unit costs are less than Metropolitan water rates, up to a maximum of 25 years. A similar Metropolitan program provides a rebate of $250 per AF for projects which increase or restore groundwater production.

It is recognized that increasing water rates are themselves an economic incentive to develop recycled water projects. However, it has been two years since the LPP rebate has been examined. In light of the discrepancies between the groundwater recovery program, and the importance of developing recycled water projects, it would be beneficial to re-evaluate the economic incentive Metropolitan provides to recycled water projects.

It has been suggested that the marginal cost of water supplies to Metropolitan is as low as $100 per AF, the cost of water transfers. This would suggest that the current LPP is adequate. However, estimating the marginal cost of new water at $100 per AF is simplistic, and neglects the variable and fixed cost of delivering water into and throughout the Metropolitan system. The attached chart suggests an estimate of marginal water supply cost of up to $910 per AF. Marginal cost should include not only acquisition, but transport, energy and environmental costs as well.

The economics of water in California suggest several topics of discussion for water leaders. If the marginal cost of new imported supplies can reach $910 per AF, is it not worth examining our economic incentives to develop dependable local supplies? Is the LPP rebate of $154 per AF sufficient? What are the impacts of the LPP rebate on the overall Metropolitan rate structure? A detailed study evaluating the regional economic benefits of recycled water is in order, as a prelude to vigorous, thoughtful action.

Marginal Cost of Additional State Water Supplies



WATER RATES

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the median usage, to think about ways to cut back on their consumption.

Multi-family customers, business and industry would be charged at the high block rate when their consumption in the summer exceed 125% of their average winter use. This allows for more usage in the summer at the low block rate to cover irrigation needs, but maintains the conservation ethic. Each business or industry would establish its own basic needs according to its winter use.

During shortage years, when we experience drought and need to cut back, instead of mandatory conservation with penalties that can be inequitable and are an administrative nightmare, the Blue Ribbon Committee recommends lowering the break point between low and high block rates in direct proportion to the degree of shortage, and increasing the cost of the high block rate to reflect the new marginal cost of additional water during the drought. The low block rate would remain the same to insure that those who do conserve are not penalized.

One other recommendation of the Blue Ribbon Committee recognizes the importance of expanding our ability to reuse reclaimed water. It recommends that an adjustment factor be added to all block rates to recover the costs of both conservation and reclamation projects that have been approved by the DWP Commission.

This will become a part of the extra charge for purchased water that has to be a part of every water bill. To keep the bill simple and easy to understand, another goal of the Blue Ribbon Committee, these adjustments will be added to the block rates before appearing on bills.

It is truly heartening that the group of citizens from all walks of life and from many different communities within the city that served on the Blue Ribbon Committee all agreed on the importance of water reuse and have made it the centerpiece of their recommendations to the city.

Lake Balboa Opens

City residents will be able to enjoy a new 27-acre recreational lake in the San Fernando Valley thanks to the efforts of the City, the U.S. Army Corps of Engineers, federal officials and local community leaders. Lake Balboa, located in the Sepulveda Basin, has been filled with 72 million gallons of reclaimed water from the Tillman Water Reclamation Plant.

"At long last, Valley residents have a lake nearby to use for fishing and boating--or just to enjoy as scenery when they picnic and play in Lake Balboa Park", said Congressman Anthony Beilenson. "It took many years to plan, obtain funding, build, and finally fill Lake Balboa, so this is a moment for all of us to celebrate and take pride in our achievement."

Said Mayor Bradley to the assembled citizens: "This is your water. You've already used it at least once. Take it!"

Turning on the water at Lake Balboa: (l to r) City Council Members Marvin Braude and Joy Picus, Jackie Tatum (Dept. of Recreation & Parks), Colonel Robert Van Antwerp (U.S. Army Corps of Engineers), Congressman Anthony Beilenson, Mayor Tom Bradley, and DWP Commission President Mike Gage. Not pictured: Felicia Marcus, President of the Board of Public Works.

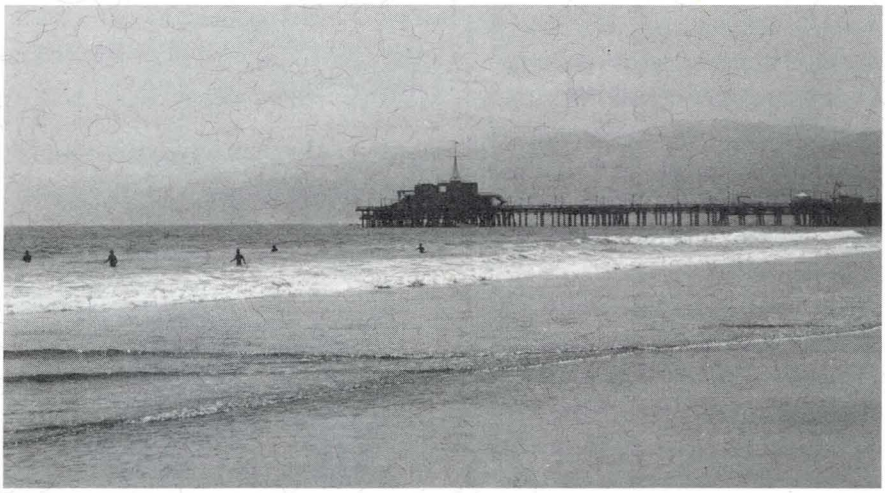
Recycling May Cure Storm Drain Problem

Storm drain water can carry unsightly or polluted material to the ocean. If a special water reclamation plant is built as planned, this source of ocean pollution will be reduced. The City of Santa Monica, together with the City and County of Los Angeles, is considering constructing the new plant to receive storm water that now flows to the ocean through the Pico/Kenter storm drain, about a half-mile south of the Santa Monica pier. If approved, planners hope to have the plant in operation by 1995.

Storm drain water is a serious pollution problem at beaches and in coastal waters in Southern California. Pollutants, including illegally dumped chemicals, can collect in the storm drain system during dry periods. Storms can wash these pollutants to the ocean, sometimes causing water pollution levels to rise so much that the County warns swimmers to stay out of the water. In addition to chemical pollutants, biologically hazardous material is sometimes present.

The new plant would treat the storm water for recycling for irrigation and other uses.

The plans to take the potentially hazardous storm water and reclaim it for good use again demonstrate the essential benefit of water recycling: the ability to convert a waste product to a useful, valuable resource.



Storm water recycling may reduce a source of pollution harming the Santa Monica Bay.

DWP Begins East Valley Design

The Los Angeles Department of Water and Power began the detailed design phase of the big East Valley Water Reclamation Project in July. The project will use up to 50,000 acre-feet of reclaimed water per year for groundwater recharge, landscape irrigation and industrial processes. DWP expects to complete the design by August, 1993, in line with a planned 1995 completion date.

The East Valley Project is one of the largest water reclamation activities planned in California. The project will pump reclaimed water from the Tillman Water Reclamation Plant in Van Nuys 13 miles to the Sun Valley area of the San Fernando Valley.

DWP has released one engineering report for the project, detailing all non-groundwater activities. A second report, dealing with groundwater recharge, has been delayed so that a mathematical model of groundwater movement could be utilized. Engineers expect the report to be completed by the end of the year.

Groundwater recharge is one of the safest uses of reclaimed water. One study found that golfing on a golf course irrigated with reclaimed water presented virtually zero possibility of a person coming into contact with any harmful material. Contact as a result of groundwater recharge was 10,000 times less likely than even this minuscule possibility.

Groundwater recharge is also relatively inexpensive. Reclaimed water delivered through the East Valley project will cost significantly less than new supplies of potable water.

County Plans To Double Reclamation by 1995; City Also Making Progress

Los Angeles County, respected nationwide as a leader in water reclamation and the largest purveyor of reclaimed water in California, plans to double its use of the valuable resource by the end of 1995. The County recycled more than 62,000 acre-feet (AF) in fiscal 1991-92, and plans to reuse more than 130,000 AF by late 1995.

The County's accomplishments tower above those of most other developers of reclaimed water. The City of Los Angeles, for comparison, recycled 6,600 AF of water last year. However, the City is making headway. The City plans to recycle approximately 64,000 AFY by late 1995. The total includes 10,000 AF at the East Valley Project, 20,000 AF at Lake Balboa and 22,000 AF in connection with the big multiple-use project spearheaded by the West Basin Municipal Water District.

Groundwater recharge has played the most prominent role in the County's water recycling efforts. Recharge of groundwater basins accounted for two-thirds of the County's use of reclaimed water last year. It will account for the lion's share of the planned expansion as well, with the Upper San Gabriel Valley project alone using 28,000 AFY for groundwater recharge. The City also will rely on this technology, especially at the East Valley and West Basin projects.

Although more effort will be needed to fully develop the potential of reclaimed water, success is all but assured if the City and the County continue to strive for leadership in this field.

The Future Is *Potable* Reuse

Tertiary-treated and disinfected reclaimed water is almost drinkable. That is why public health officials are comfortable with its unrestricted non-potable uses. What does it take to be able to declare it safe--without qualification--for long-term drinking use? The answer is: a great deal more treatment. Upper Occoquan Sewage Authority (UOSA) produces recycled water to supplement a 55 acre-foot drinking water reservoir for a Virginia suburb of Washington, D.C. The purification process used at the UOSA plant includes activated sludge secondary treatment, phosphorus removal by lime coagulation, recarbonation, nitrogen removal by ion exchange, mixed-media filtration, activated carbon adsorption, and breakpoint chlorination.

Such extensive treatment, accompanied by constant monitoring and frequent reporting, ensures a water supply that surpasses the quality and reliability of nearly all other water supplies that municipalities normally employ. Thus, the technology is demonstrably here, now, for a very reliable potable supplement from recycled water. What is lacking, however, is a sound and practical regulatory framework. Recently, a group of interested individuals from the public, private and regulatory sectors throughout the state formed a committee to create such a framework. In its first meeting, the committee hammered out this initial mission statement:

"Gain public and regulatory acceptance to implement safe water recycling for direct augmentation of potable surface water supplies."

Here is a water recycling project that does not require dual plumbing, just enough transmission to get the reclaimed water from the treatment plant to the reservoir. In future issues we will explore the economics of the additional treatment needed for potable use vs. the costs of dual plumbing for non-potable uses. Stay tuned.

CALENDAR

Water Environment Federation 65th Annual Conference. September 20-24, 1992, New Orleans, LA. (Two Reuse Sessions: 23, 49).

WateReuse Annual Symposium VII. San Francisco Marriott. October 7-9, 1992, call (916) 442-2746.

GRAY = GREEN², WateReuse/DWR. November 18-19, 1992, Los Angeles, CA. Includes a tour of 4 gray water installations. Call (916) 442-2746.

Water Consensus II, Local Government Commission. Los Angeles Biltmore Hotel, November 20-21, 1992.

Joint Management Conference. February 28-March 3, 1993, Altlanta, GA. Sponsored by WEF, AWWA. Call (303) 794-7711.

CONSERVE '93: The New Water Agenda. December 12-16, 1993, Las Vegas, Nevada. Call for papers at AWWA (303) 794-7711.

OWR NEWS is published by the **Office of Water Reclamation**, Room 366, City Hall, 200 N. Spring St., Los Angeles, CA 90012; (213) 237-0887. We welcome submissions of articles and story ideas. The **Office of Water Reclamation** reserves all editorial rights.

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Abbas Amirteymoori, Environmental Engineer
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RESOURCES

For information on the following publications, call (213) 237-0887:

* **City of San Diego Potable Reuse of Reclaimed Water: Final Results,** by Ken Thompson et al.
* **Desalting & Recycling, Meeting Today's Water Challenges,** 2 volumes, proceedings of the NWSIA 1992 Biennial Conference, August 1992. Call for Table of Contents or come into the office to browse.
* **Ozone Application in Water Treatment - Is it a Better Alternative to Chlorine?**
* **Well-Head Treatment with Granular Activated Carbon for Removing Organics From San Fernando Valley Basin Groundwater: A Preliminary Study.**

OWR NEWS

Newsletter of the
Office of Water Reclamation
Room 366, City Hall
200 North Spring Street
Los Angeles, CA 90012

TO:

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tance of their crops. There can be public health concerns that must be allayed regarding disease-causing micro-organisms when reclaimed water is used in areas where contact with the public is possible. Regulatory agencies are often concerned with the possibility that surface water or groundwater may be polluted as a result of irrigating with reclaimed water.

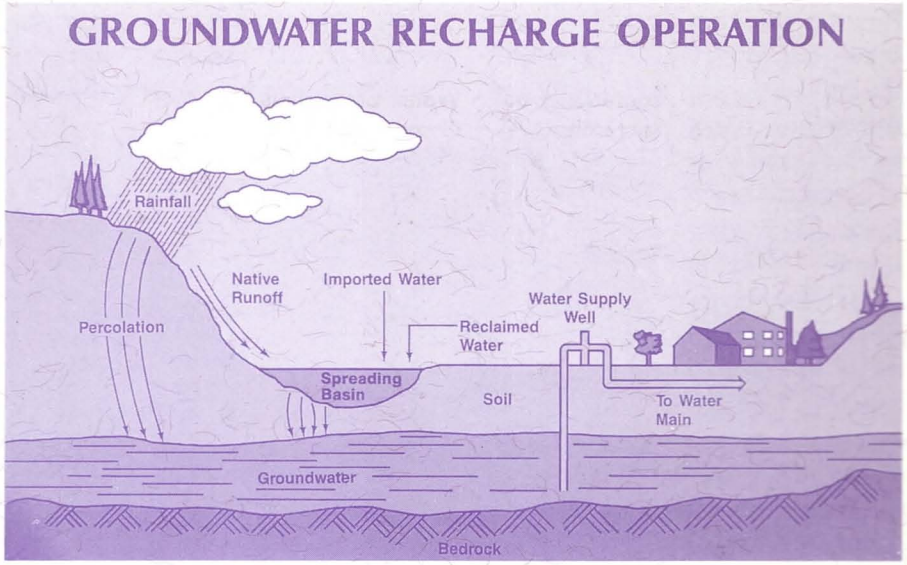
An additional benefit of using reclaimed water for irrigation is that it normally contains key plant nutrients such as nitrogen and phosphorous. Thus, use of reclaimed water can reduce both water costs and fertilizer costs.

Industrial Uses

Industries need dependable water supplies, and reclaimed water offers the advantage of a reliable supply during a drought or water shortage. The largest industrial use is for cooling and process water. Cooling systems which recirculate the water, rather than using a "once-through" process, generally require a high quality supply to reduce scaling, corrosion, biological growth, or other fouling problems that reduce efficiency.

Groundwater Recharge

In some areas of the country, groundwater recharge with reclaimed water offers potentially large reuse opportunities at low cost. Groundwater recharge is achieved by either injecting highly treated reclaimed water into groundwater aquifers through a well, or spreading it on the surface and allowing it to percolate into the ground. The reclaimed water serves either to create a barrier which prevents seawater from seeping into the basin (in coastal areas), or to replenish water that has been removed through pumping.



Groundwater recharge can be a large-scale, low-cost use of reclaimed water

In spite of its promise, this application has been approached cautiously due to public health concerns about the long-term effects associated with synthetic organic compounds and other constituents that may be present in the reclaimed water. In California, the Orange-Los Angeles Counties Health Effects Study conducted from 1978 to 1984 included an extensive investigation of the potential health effects of using reclaimed water to recharge potable water aquifers. The study looked at the effectiveness of treatment processes, removal of remaining contaminants by percolation through the soil, quality of waters eventually reaching consumers, and the epidemiology of populations receiving certain percentages of reclaimed water in their potable supply over a long period of time. This study, and other follow-up work, led to the development of guidelines for groundwater recharge projects in California.

Recreational and Environmental Uses

Reclaimed water can be used in impoundments, streams and wetlands to enhance recreational opportunities, scenic quality, and wildlife habitat. Artificial lakes have been created which are popular for picnicking, fishing, and boating. Marshes, lakes, and streams are being supplemented with reclaimed water to provide valuable wildlife habitat. Reclaimed water is also gaining popularity with landscape architects for use in ornamental water features at golf courses, commercial buildings, and parks.

Potable Reuse

Direct reuse of reclaimed water into a potable water distribution system is currently not allowed or practiced in the United States or

Canada. Indirect potable reuse, where reclaimed water mixes with natural water and the mixture is ultimately used for municipal water supply, is practiced to a limited extent. This is particularly true when reclaimed water is used to recharge groundwater basins. However, examples of mixing reclaimed water with natural waters in large surface storage reservoirs can also be found. Ongoing health effects studies at pilot-scale research projects in San Diego, Tampa and Denver should influence future decisions regarding this potential use of reclaimed water.

Los Angeles residents enjoy Lake Balboa, which is filled with reclaimed water

WHAT ARE THE OBSTACLES?

Water reclamation projects and reuse programs face a variety of obstacles to implementation. The least of these obstacles appears to be technology, which is generally well developed and available. Experts agree that the problems of paying for the capital facilities (typically the advanced treatment facilities and distribution system) are among the most difficult to solve, particularly during startup. During the early years of a program, reclaimed water sales are frequently not enough to cover the front-end costs of capital, and the program must also be supported by potable water supply customers and/or sewer users. Questions arise as to who benefits and how much of the bill they should pay.

Other common obstacles to implementation are public health concerns and general public attitudes about contact with reclaimed water. Extensive public opinion surveys in California have revealed that this obstacle may be becoming less of an issue as the public becomes better informed about the safe use of reclaimed water and as public advocacy increases for conservation of water and the environment. However, it is clear that uses with a high degree of public contact are less acceptable to health agencies and the general populace, and are more difficult to implement.

Concerns about water quality are sometimes a stumbling block, particularly if a reclamation and reuse program is based on using reclaimed water for irrigation. Compared to freshwater supply, reclaimed water typically has higher concentrations of dissolved salts and other constituents which, if too high, can be detrimental to irrigated soils and plants. This is an issue which varies considerably from one location to another, and it should be assessed at the outset of each program. If problems exist, possible solutions include source control programs to reduce the discharge of contaminants to the sewer system, additional advanced treatment to remove the problem constituents, and changes in irrigation practices and techniques.

WHAT IS THE FUTURE OF RECLAIMED WATER?

Water reclamation and reuse will play an increasingly important role in water resource management. Use of reclaimed water will become even more attractive economically as new supplies of fresh water become more scarce and expensive to develop. Traditional uses of reclaimed water such as agricultural and landscape irrigation will continue to expand. Exciting and innovative programs in industry, commercial buildings, recreational facilities, and the environment will create new markets for reclaimed water. The use of reclaimed water to recharge groundwater basins, and the subsequent use of these groundwater basins for public water supply will increase dramatically, particularly in the arid Southwest U.S. and Florida.

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LONG-RANGE PLANNING FOR WATER REUSE IN THE CITY OF LOS ANGELES

Bahman Sheikh

Office of Water Reclamation, City of Los Angeles, Room 366, City Hall, 200 North Spring Street, Los Angeles CA 90012, USA

ABSTRACT

While new sources of affordable potable water for Los Angeles will likely decrease or be unavailable in the future, sources of readily usable reclaimed water will double over the next decade. For many non-potable uses (e.g., landscape irrigation, industrial cooling, toilet flushing), reclaimed water can replace potable water, thereby making equivalent volumes of potable water available. Groundwater recharge with reclaimed water can further augment potable water supplies in significant volumes. Quantitative goals for water reuse were derived by comparing projected water demands with predicted dependable supplies. These goals are to reuse 40, 70, and 80 percent of the total effluent by the years 2010, 2050, and 2090, respectively. In this planning study, several water reuse concepts were evaluated for near-, mid-, and long-term application. For the near-term, several immediately implementable water reuse projects are recommended, involving landscape irrigation, industrial cooling and groundwater recharge. For the mid-term, massive groundwater recharge in San Fernando Valley and in Central and West Coast Basins is recommended. For the long-term, potable reuse and/or groundwater recharge appear to be the best options.

KEYWORDS

Water reclamation; water reuse; urban reuse; reuse planning; groundwater recharge; industrial reuse.

INTRODUCTION

The City of Los Angeles has historically depended heavily on imported sources of water supply for its growing needs. Those sources are now becoming more difficult to expand due to higher environmental and construction costs. Some of the imported water supplies will be reduced significantly in annual yield; for example, greater withdrawals by the State of Arizona are expected as the Central Arizona Project components are completed. Others have been cut back by interim court orders. The reduced water supplies will become even more stressed as regional and state-wide water policies take effect and as increasing populations demand greater volumes of water.

Water reclamation represents an ideal method of augmenting this increasingly scarce commodity. A primary goal of the City of Los Angeles is therefore to maximize its use of reclaimed water.

WATER RECLAMATION GOALS

The method chosen for quantifying the goals for the planning horizons of this study is to review the water supply and demand projections within the City of Los Angeles. In Table 1, a uniform 200 gallons per capita per day water consumption factor is used to project water demands into the future. Dependable water supply for the year 2010 is based on volumes deliverable with the existing water supply facilities, while those for the year 2090 involve development of new sources and construction of new facilities. Interim supplies were obtained by linear interpolation.

TABLE 1 City Of Los Angeles Water Reclamation Goals Based On Balancing Supply vs. Demand Deficit

	Short-Term ~2010	Mid-Term ~2050	Long-Term ~2090
Population, millions[a]	4.86	6.51	7.66
Water Demand, KAFY[b]	1,089	1,458	1,716
Dependable Water Supply, KAFY[c]	893	997	1,100
"New Water Req., KAFY[d]	255	601	801
Reclaimable Wastewater, KAFY[a]	661	874	1,042
Percent of Effluent to Reclaim[e]	39%	69%	77%

[a] Population and flow data are based on the assumption of even population distribution
[b] Water demand assumed uniform consumption of 200 gpcd ; AFY = acre-feet per year
[c] Dependable water supply is based on current projections, excluding reuse
[d] "New" water requirement is the difference between 2 and 3, plus 30 percent to account for conservative flow estimates
[e] Portion of the wastewater effluent that would, if reused, supply the shortfall

Data in Table 1 point out that about 40 percent of the wastewater will need to be reclaimed to satisfy the City's short-term needs and 70 percent for the mid-term shortfall. For the long-term, this proportion increases to 77 percent or about 800,000 AFY (900 mgd).

WATER REUSE STRATEGIES TO ACHIEVE GOALS

The process of planning for water reuse will be treated as a dynamic one, with frequent periodic updates based on the most recent state of the technology, public attitudes, regulatory requirements, and economics. In the last decade, significant shifts in all these areas have caused many reuse prospects that were infeasible before to become much more attractive. Strategies described below are being used to accelerate the rate of progress toward achieving the above goals.

Water Reclamation Strategies

Limitation of the "Option" To Use Reclaimed Water. This strategy would involve eliminating or limiting certain users' option of selecting potable supplies over reclaimed water. The City is considering this option through adoption of a Water Reclamation Ordinance, complementing similar requirements in the State Water Code.

Coordination with Local and Regional Agencies. Water reclamation activities of the City of Los Angeles are being coordinated with local and regional water purveyors, health authorities, and other

involved agencies with an interest in the generation, treatment, conveyance, and use of reclaimed water. A greater definition of each agency's role, however, needs to be established on a continuing basis.

Development of Short- and Mid-Term Water Reclamation Concepts. Various projects and programs are being initiated at the present time in conformance with existing City policies regarding water reclamation and reuse. Funding is being established through the normal capital improvement budgeting process at the Department of Water and Power for large-scale water reuse, including a City-wide distribution system for reclaimed water.

Public Information Workshops and Publicity Campaigns for Water Reclamation and Reuse. The importance of an informed public to successful implementation of water reclamation and reuse in the City of Los Angeles cannot be overemphasized (1). Public information campaigns are being initiated on the benefits of reclamation and reuse.

DESCRIPTION OF WATER REUSE CONCEPTS

The alternative concepts presented below are formulated, recognizing the City's existing wastewater conveyance and treatment facilities and the potential for their future expansion and modification.

Near-Term Water Reclamation Opportunities

Opportunities for future expansion of the use of reclaimed water in the City of Los Angeles are extensive, covering nearly all traditional reuse categories. Some of these categories are adaptable in the near term and some in the long term. The near-term reuse opportunities are essentially those identified and characterized in the 1982 OLAC study (2,3). Some of these opportunities are currently being translated into actual projects. With staged construction of needed distribution facilities, these and several larger projects are expected to be completed over the next 20 years.

Mid-Term Water Reclamation Opportunities

Even though the mid-term planning horizon is associated here with the year 2050, it is expected that different water reclamation opportunities and schemes will mature over several decades around the year 2050.

Groundwater Recharge and Seawater Intrusion Barriers. Artificial recharge of groundwater reservoirs with reclaimed water has been practiced for a long time in various parts of the country (notably Florida, Arizona, and Texas). Artificial recharge provides a convenient means of balancing the high summer demands for water with the relatively uniform supply from wastewater treatment plants. Groundwater recharge usually involves introduction of water at some point into the aquifer and withdrawals at points some distance removed, after slow travel through the aquifer's porous media. A large-scale, long-term, controlled study was recently completed in Los Angeles County. Epidemiological characteristics of populations drinking water from aquifers recharged with reclaimed water versus those receiving surface runoff showed no detectable differences (4).

Recharge wells specifically designed for injection of water along the coastline to counter inland movement of saline seawater are a special application. Such barrier injection wells using tertiary treated effluent are in current use in the coastal area of Orange County where highly treated water produced at Water Factory 21 is used to recharge the Talbert Gap Barrier Project. The potential for use of reclaimed water in these applications in the City of Los Angeles has been studied in the past, but a project has yet to be implemented.

The draft proposed California Policy and Guidelines for Groundwater Recharge with Reclaimed Municipal Wastewater are currently under review. These guidelines provide numerical criteria for input water quality, vertical distance from the water table, horizontal distance to nearest withdrawal wells, and residence time in the aquifer. The guidelines are expected to be published in final form in 1992.

One of the advantages of groundwater recharge is that large volumes of reclaimed water can be used in the operations, whereas other alternatives depend on relatively large irrigable areas and dispersed points of industrial demand. The San Fernando Valley Groundwater Basin has an estimated capacity of about 3.2 million acre-feet (ac-ft), of which about 2.7 million ac-ft are currently being used. This leaves a capacity of approximately 0.5 million ac-ft for annual recharge and recovery.

Two of the City of Los Angeles's water reclamation plants are ideally situated for large-scale groundwater recharge operations. Although existing spreading grounds are located at considerable distances from these facilities, preliminary cost estimates indicate that groundwater recharge projects are more cost-effective than landscape irrigation or industrial applications of reclaimed water.

Export of Reclaimed Water to San Joaquin Valley. The farming enterprises in San Joaquin Valley use large volumes of water to raise a variety of crops. Reclaimed water, if conveyed to some of these farms in a transmission system from Los Angeles, could be substituted for potable water currently used. Water exchange agreements would be needed to swap an equivalent volume of firm agricultural water to be transported to Los Angeles. Possible incentives for farmers to accept this kind of exchange include: dependability (uninterruptability) of supply, delivered on demand, under pressure; nutrients in reclaimed water, saving some fertilizer costs (with some crops, nutrients must be limited at crop maturity); potential cost savings and incentive subsidies.

For such a concept to be successful and economically attractive, very large volumes of reclaimed water would need to be transported from the basin. Enabling state legislation may be required for major transmission pipelines to cross numerous county lines and other jurisdictions. Already, the feasibility of using directly filtered secondary effluent on the most sensitive crops (lettuce, broccoli, celery, cauliflower, etc.), from a public-health perspective has been demonstrated and approved by the California Department of Health Services (CDHS) (5) through a long-term demonstration project in Monterey County.

Satellite Plants. This concept involves one or more treatment plants in upstream locations (in addition to existing upstream plants) to draw from major sewer interceptors and treat the wastewater adequately for reuse at locations near each "satellite" plant. Each wastewater treatment facility--existing, planned, and additional ones as needed--would be designed as a water reclamation plant, treating water to tertiary level, meeting Title 22-requirements. Reclaimed water from these plants would be usable for a wide variety of landscape, industrial, and recreational (including body-contact) uses. Distribution networks, radiating from each water reclamation plant would serve the local water users, with adequate capacity for expansion, as demand increases and additional users are served.

Long-Term Water Reclamation Concepts

The long-term opportunities for water reclamation are expected to expand dramatically because of the anticipated trends and changes producing different future scenarios and conditions, such as the following.

- Population pressure will be greater and "drought" occurrences--deficit of supply vs demand--will be more severe and more frequent, giving rise to greater public and regulatory support for all reuse options.

- Costs of development of new sources of potable water supply will be so much higher that the apparent relative cheapness of existing water sources will no longer be an economic obstacle.

- Wastewater treatment requirements and wastewater discharge prohibitions to receiving waters are expected to become so much more stringent in the future that they will play a significant part in: (1) making it necessary to place the effluents in environmentally acceptable locations (e.g., on the land), and (2) reducing the cost of incremental treatment, because removal of more contaminants to a greater degree will be mandated, as a condition of discharge.

- Technological advances in water and wastewater treatment will increase the reliability of treatment and possibly reduce costs for advanced treatment processes such as nutrient removal, filtration, granulated activated carbon, and demineralization. These advanced treatment unit processes will become more common at the water reclamation plants of the future.

- The regulatory climate is expected to respond to the practically risk-free operational experience obtained at the over 850 locations in California reusing reclaimed water successfully, some for several decades. As a result, it is expected that many existing constraints to water reclamation will become less prohibitive.

Groundwater Recharge. Various forms of groundwater recharge with reclaimed water are expected to become even more technically feasible toward 2090 than in the mid-term planning horizon. It is anticipated that the entire reclamation goal of the City of Los Angeles for 2090 can be met with use of the Central Basin and the San Fernando Basin aquifers for water storage. Unused capacity in these basins totals over one million acre-ft.

Export of Reclaimed Water to San Joaquin Valley and Exchange with Agricultural Water. The long-term export option is very similar to the mid-term export option described earlier, except in the volume of reclaimed water it would exchange for agricultural water. It envisions using not only reclaimed water from the City of Los Angeles water reclamation plants, but also from neighboring jurisdictions. For the purposes of cost evaluation, it was assumed that reclaimed water from the Los Angeles County plant in Carson would supplement that from the four existing plants operated by the City of Los Angeles.

Direct Potable Reuse. Toward the latter part of the 21st century, it is envisioned that direct potable reuse will become relatively widespread in the dry areas of the United States and many other countries. Los Angeles and surrounding communities will probably be leaders in the scale of operation and the level of protection afforded for the health of the consumers. Currently, the Denver Water Board is conducting long-term animal feeding tests under Environmental Protection Agency (EPA) supervision and partial funding, using 500-fold concentrates of both reclaimed water and Denver's domestic supply. The concentrates magnify organic compounds remaining in the waters to estimate potential adverse health effects. Thus far, renovated water has compared favorably. Final results are expected in 1992.

A major advantage of direct potable reuse is that a separate distribution system is not necessary to convey the finished water to the consumer. It is envisioned that the product water would be released into the water reservoirs or raw water storage facilities for blending with treated water from imported sources.

EVALUATION OF WATER RECLAMATION ALTERNATIVES

Water reclamation alternatives were compared on the basis of monetary and nonmonetary criteria. Monetary criteria include total and annualized capital and operation and maintenance costs. Nonmonetary evaluation criteria play an equally important role in comparing wastewater reclamation alternatives.

Costs of most of the near-term alternatives are were updated from the OLAC Study (2), using the appropriate ENR construction cost index ratios. The unit costs of the alternative reuse concepts are summarized in Table 2.

TABLE 2 Costs Of Convenience Pumping, Distribution, Treatment For Near-Term Water Reuse Alternatives

Alt. No.	Reclaimed Alternative	Volume Cost (ac-ft/yr)	Total ($/ac-ft)
N-1	Industrial Reuse	5,800	500
N-2	A Greenbelt Expansion	2,200	900
N-3	Dual Distribution	100,000	800
N-4	Sepulveda Basin	8,850	800
N-5	Burbank-LA Greenbelt	1,100	500
N-6	Groundwater Recharge	35,000	600
N-7	Seawater Intrusion Barrier	20,000	600

Dual distribution and industrial cooling costs were directly estimated. Seawater intrusion barrier costs are assumed to be equal to those of groundwater recharge.

Because of their distant future applicability and the attendant uncertainties, the mid-term and the long-term reuse concepts are evaluated together, and compared with one another. In fact, cost estimates for these alternatives are not escalated to their respective years, but calculated with 1990 dollars. Costs of treatment for the various reuse alternatives were based on present-day and near-term regulatory criteria governing water reclamation. Table 3 presents a summary of the required treatment levels and related costs for different treatment plant size configurations.

CONCLUSIONS

The unit cost spread among the near-term alternatives is narrow enough to make them almost equivalent. None of the alternatives has a "fatal flaw" for implementation in the near term. Furthermore, no one of these alternatives singly results in a major volume of water reclamation. Therefore, it is concluded that all seven options--and other similar projects--should be implemented in parallel for the near term. Site-specific alternatives can be developed during facility planning.

A comparison of all the mid- and long-term concepts favors the satellite plants concept over all others. This is followed by groundwater recharge. Potable reuse is very close; it is second place in cost. The export and exchange concept is the least cost-effective of all alternatives mainly because of its very high unit cost. The best immediate course of action, for the mid- and long-term alternatives, appears to be initiation of demonstration and pilot projects for both the groundwater recharge concept and direct potable reuse.

TABLE 3 Costs Of Conveyance And Treatment For Mid- (2050) And Long-Term (2090) Water Reuse Alternatives

Alt. No.	Alternative Concept	Volume Reclaimed (AFY)[b]	Present Worth (10^6)	Conveyance Costs[a] Annual Cost (10^6)	Unit Cost ($/AF)	Treatment Cost ($/AF)	Total Cost ($/AF)
M-1	Groundwater Recharge	427,700	1,307	134	310	800	1,110
M-2	Export to San Joaquin	237,300	4,124	382	1,610	400	2,010
M-3[b]	One Satellite Plant[c]	140,000	429	40	290	120	410
M-3[a]	Eight Satellite Plants	140,000	408	38	270	180	450
L-1	Groundwater Recharge	720,000	1,451	206	290	800	1,090
L-2	Export/San Joaquin	1,150,000	9,580	1,518	1,320	400	1,720
L-3	Potable Reuse	720,000	768	129	180	1,025	1,205

[a] Conveyance costs include transmission, pumping, and distribution.
[b] AFY = acre-feet per year
[c] The satellite-plants costs were estimated for two scenarios. In one scenario, one plant was assumed to be built, with an ultimate capacity of 150 mgd. In the other scenario, eight plants were assumed.

ACKNOWLEDGEMENT

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Rules for the Reuse of Reclaimed Water

Introduction:

The Arizona Department of Environmental Quality (ADEQ) is proposing a major revision of the existing rules related to the reuse of reclaimed water. The existing rules are found in Title 18, Chapter 9, Article 7 of the Arizona Administrative Code [See A.A.C. R18-9-701 through R18-9-707 in Appendix 1]. ADEQ proposes to repeal these rules and to integrate the reuse permit program and the Aquifer Protection Permit program.

The purpose of this concept paper is to 1) describe the statutory authority for revision of the rules governing the reuse of reclaimed water; 2) outline the proposed rulemaking strategy and public participation procedures that ADEQ will employ in the development of these rules; and 3) present the major issues for consideration.

Statutory authority:

The Environmental Quality Act requires the Director to "[p]romote and coordinate the protection and enhancement of the quality of water resources consistent with the environmental policy of this State" [See A.R.S. §49-104.A.8]. Reclaimed water is an important water resource. The reuse of reclaimed water has significant potential for augmenting available drinking water supplies through source substitution [i.e., replacing the use of potable water for nonpotable purposes]. It also can abate pollution through the elimination of effluent discharges to navigable waters. ADEQ seeks to promote the reuse of reclaimed water through the adoption of reasonable reclaimed water quality criteria and through the elimination of unnecessary regulatory barriers to reclamation.

A.R.S. §49-203.C requires the Director to integrate the administration and enforcement of Water Quality Control programs and to avoid duplication and dual permitting to the maximum extent practicable. The proposed consolidation of the reuse permit program and the Aquifer Protection Permit program will eliminate the dual permitting of wastewater treatment plants that are involved in reclamation. The integration of these two permit programs is consistent with this statutory mandate.

It should be noted that there is no specific statutory authority for the current reuse permit program. A.R.S. §49-203.A, paragraphs 2 through 5, give the Director the statutory authority to carry out water quality permit programs under Chapter 2 of Title 49 of the Arizona Revised Statutes [i.e., point source discharge permits, Aquifer Protection Permits (APP), and Underground Injection Control permits]. Unfortunately, the Legislature did not include a specific grant of authority for a reuse permit program in the general powers and duties of the Director.

Chapter 2 of Title 49 of the Arizona Revised Statutes (Water Quality Control) contains a reference to reuse permits at A.R.S. §49-250.B.8. A.R.S. §49-250.B.8 exempts from APP requirements those "facilities which are defined and required to obtain a permit to reuse reclaimed wastewater." The recognition of a reuse permit program in this exemption provision implies that reuse permitting is one of ADEQ's functions related to Water Quality Control. Therefore, general statutory authority for a reuse permit program may be found at A.R.S. §49-203.A.8. A.R.S. §49-203.A.8 gives the Director the general authority to adopt, modify, repeal and enforce rules which are reasonably necessary to carry out ADEQ's water quality control functions.

Specific statutory authority to regulate reclamation systems may be found at A.R.S. §49-104.B.13. A.R.S. §49-104.B.13 gives the Director the authority to "[p]rescribe reasonable rules regarding sewage collection, treatment, disposal <u>and reclamation systems</u> to prevent the transmission of sewage borne or insect borne diseases" (emphasis added). A.R.S §49-104.B.13 states, in relevant part, that the rules shall:

(a) Prescribe minimum standards for the design of... reclamation systems and for operating the systems.
(b) Provide for inspecting the premises, systems, and installations and for abating as a public nuisance any... reclamation system which does not comply with the minimum standards.
(c) Require that the plans and specifications for all... reclamation systems be submitted with a fee for review to the department and may require that such plans and specifications anticipate and provide for future sewage treatment needs.
(d) Prohibit construction, reconstruction, installation or initiation of any...reclamation system before the approval of the plans and specifications and of the construction by the department after payment of the appropriate fees.

This section provides the statutory authority for ADEQ to establish reclamation criteria and to require the submission of design plans for wastewater treatment plants and reclaimed water distribution systems. It provides the legal basis for technical review requirements, including Approvals to Construct and Final Approvals of Construction. The statute also provides authority for ADEQ to inspect wastewater treatment plants, reclaimed water distribution systems and reuse sites and to charge fees.

Rulemaking Strategy:

ADEQ's rulemaking strategy is intended to assure public participation in the development of the rules governing the reuse of reclaimed water and to meet the requirements of the State Administrative Procedures Act [APA]. The rules will be proposed in accordance with ADEQ's general administrative rules governing

rulemaking found in Title 18, Chapter 1, Article 3 of the Arizona Administrative Code and the APA.

Critical review of ADEQ's rulemaking effort by the regulated community, by citizens interested in promoting the reuse of reclaimed water and by citizens concerned about the impacts of the reuse of reclaimed water on public health and the environment will provide the best assurance that reasonable rules will be developed.

The first step in the informal rulemaking process is the development of a concept paper and/or preliminary draft rules [See Appendix 2: Flow Chart of the Rule Adoption Process]. The distribution of this concept paper represents the first step in a rulemaking process that ADEQ expects will take more than a year to complete.

ADEQ will schedule a series of public meetings to discuss issues raised by the concept paper [See tentative rule development schedule on the following page]. Notice of all public meetings will be posted on the bulletin board located in the lobby of ADEQ's main office building at 3033 N. Central Avenue in Phoenix. Notice also will be published in the ADEQ Rulesletter. The ADEQ Rulesletter is a newsletter that is published monthly by the Rule Development Section and is available upon request. You can also call the ADEQ Automated Information Line at 207-4300 to obtain up-to-date information on current rule developments related to reuse.

ADEQ encourages the active participation of interested members of the public in this rulemaking effort and invites the submission of written public comments on the concept paper. Written comments may be addressed to:

Department of Environmental Quality
3033 N. Central Avenue, Room 825
Phoenix, Arizona 85012
Attn: Mr. Steven Pawlowski

Telephone inquiries regarding the concept paper or the specific locations and times of public meetings on the reuse rules may be directed to Mr. Pawlowski at 207-2227.

Tentative Rule Development Schedule

Distribution of concept paper	November, 1992
Public meetings	November and December, 1992
Development of preliminary draft APP and Sewage System rules;	January, 1993
Public meetings on preliminary draft rules	January and February, 1993
Development of economic impact statement and proposed rules; submittal of proposed rules to the Office of Strategic Planning and Budgeting	March, 1993
Publication of notice that proposed rules will be considered by the Governor's Regulatory Review Council	April, 1993
Governor's Regulatory Review Council	May, 1993
Publication of Notice of Proposed Rules in Administrative Register	June, 1993
Oral proceedings	July, 1993
Close of comment period on proposed rules	August, 1993
Adoption of rules by the Director	October, 1993
Attorney General certification	December, 1993
Estimated effective date	January, 1994

Reclaimed Water Reuse Issues

A. SCOPE

1. What is the scope of the existing reuse rules?

The existing rules establish reclaimed water quality criteria and a permit program to regulate the reuse of reclaimed wastewater. The "reuse of reclaimed wastewater" is defined in the existing rules as "the use of reclaimed wastewater transported from the point of treatment to the point of use without an intervening discharge to the surface waters of the State for which water quality standards have been established" [See A.A.C. R18-9-701.1 in Appendix 1].

The current rules do not regulate the discharge of reclaimed water to navigable waters: "[d]ischarges of effluent into waters of the United States require an NPDES permit and are not regulated by this Article" [See A.A.C. R18-9-702.G in Appendix 1].

Under the existing rules, the discharge of reclaimed water to an aquifer is not exempt from the requirements of regulatory programs designed to protect ground water quality. The existing reuse rules state that "[n]othing in this Article is intended to exempt disposal of reclaimed wastewater from the requirements of A.A.C. Title 9, Chapter 20, Article 2" [See A.A.C. R18-9-702.L]. This is a cross-reference to the Groundwater Quality Protection Permit Program, the predecessor of the Aquifer Protection Permit program.

In general, the existing rules apply to what is often called "direct reuse" [i.e., no intervening discharge to a navigable water or to an aquifer]. The existing rules have no application to "indirect reuse" [i.e., the diversion and use of effluent that has been discharged to a navigable water, stored underground or used for ground water recharge].

The existing rules recognize several reuse applications. In general, the existing rules regulate the reuse of reclaimed water for agricultural irrigation, landscape irrigation, livestock watering, industrial reuse applications, wetlands marshes and the use of reclaimed water in recreational impoundments [See A.A.C. R18-9-703 and Table 1 in Appendix 1].

The existing rules regulate the reuse of effluent from on-site wastewater treatment plants for landscape irrigation [See A.A.C. R18-9-703.C.5 in Appendix 1]. The rules also apply to the reuse of gray water from single-family and multi-family residences [See A.A.C. R18-9-703.C.6 in Appendix 1]. The existing rules do not apply to the sub-surface disposal of effluent through leach trenches, mound disposal systems and evapo-transpiration beds.

The existing rules regulate the reuse of reclaimed water to create

a wetlands marsh and the addition of reclaimed water to an existing man-made wetlands marsh [See A.A.C. R18-9-703.C.7 in Appendix 1]. They do not apply to the discharge of reclaimed water to a natural wetlands or to the creation of a wetlands in a navigable water. Such discharges are regulated under the water quality standards and NPDES permit programs.

The existing rules regulate the reuse of industrial wastewater if it contains sanitary waste of human origin or if it is reused for irrigation of food crops [See R18-9-703.C.8 in Appendix 1]. Industrial reuse is evaluated on a case-by-case basis to determine the appropriate reclaimed water quality criteria. In general, ADEQ considers the degree of human exposure to reclaimed water by the general public and the potential for contamination of the industrial products or byproducts in establishing reclaimed water quality criteria for industrial reuse.

Finally, the existing rules regulate wastewater treatment plants that supply reclaimed water for reuse. Operators of wastewater treatment plants are prohibited from releasing reclaimed wastewater for reuse without a reuse permit from ADEQ [See A.A.C. R18-9-702.C in Appendix 1]. The existing rules also regulate the use of partially treated wastewater for irrigation that is part of a wastewater treatment process [See A.A.C. R18-9-704 in Appendix 1].

2. **What is the scope of the proposed rules?**

ADEQ proposes to repeal the existing reuse rules and to eliminate the reuse permit program. This repeal does not mean that the direct reuse of reclaimed water will go unregulated. ADEQ proposes to regulate the direct reuse of reclaimed water through revisions to the existing Aquifer Protection Permit [APP] rules and the Sewage System rules.

ADEQ proposes to regulate wastewater treatment plants that supply reclaimed water for reuse applications under the APP program. ADEQ proposes to prescribe reclaimed water quality criteria and treatment requirements for wastewater treatment plants in revised APP rules. ADEQ also will propose revisions to the BADCT guidance document for municipal and domestic wastewater treatment plants to specifically address reclamation.

ADEQ proposes to regulate reclaimed water distribution systems under revised Sewage System rules. Owners of reclaimed water distribution systems will be required to submit design plans for reclaimed water distribution systems to ADEQ or to a county health department which has been delegated authority for technical review. Design criteria for reclaimed water distribution systems will be prescribed in revised Sewage System rules. Approvals to Construct reclaimed water distribution systems will be required for new distribution systems and for any modifications or extensions of existing distribution systems. A Final Approval of Construction

will be required before regular deliveries of reclaimed water to reuse sites will be allowed. Final Approval of Construction will involve a cross connection control test and either on-site inspection of the reclaimed water distribution system or submittal of as-built plans by a professional engineer.

ADEQ proposes to regulate reuse sites through the promulgation of general Aquifer Protection Permits for the reuse of reclaimed water for agricultural irrigation, landscape irrigation and for impoundments of reclaimed water.

ADEQ proposes to regulate the discharge of reclaimed water to a constructed wetland under the APP program [and the NPDES permit program if the wetland is constructed in a navigable water]. A constructed wetland may be designed as an integral part of a wastewater treatment plant or it may be intended primarily for the off-site disposal of effluent or the creation or enhancement of wetlands habitat. In either case, the discharge of reclaimed water to a constructed wetland will be regulated under an individual APP. If the constructed wetland is an integral part of the treatment process, the constructed wetland will be considered in the development of the individual APP for the source wastewater treatment plant. If the constructed wetland is intended primarily for off-site disposal of effluent or to create or enhance wetlands habitat, a separate APP would be required for the constructed wetlands.

ADEQ intends to repeal the existing permit rules that apply to the reuse of gray water. ADEQ proposes to regulate gray water systems under revised Sewage System rules. Persons who want to reuse gray water will be required to submit design plans for gray water reuse systems to ADEQ or to a local county health department which has been delegated authority for technical review. Design criteria for gray water reuse systems will be prescribed in revised Sewage System rules. However, ADEQ will not address this subject in this rulemaking. ADEQ probably will consider promulgation of rules for gray water reuse systems in conjunction with the development of rules to regulate on-site wastewater treatment facilities when those rules are promulgated pursuant to A.R.S. §49-362.A.

It should be noted that under the existing rules, individual disposal systems [including gray water reuse systems] are prohibited where the Department determines that connection to a public sewer system is practical [See A.A.C. R18-9-803.C]. ADEQ probably will retain this requirement when it revises the Sewage System rules. This requirement effectively prohibits gray water reuse systems in municipalities where discharge to the community sewer system is practical.

Discharges from on-site wastewater treatment plants are currently regulated under the APP program. General permits have been issued for sewage disposal systems with flows of less than 20,000 gallons

per day [gpd]. ADEQ proposes to continue to regulate these sewage disposal systems under a general APP. However, additional general permit conditions may need to be developed to protect public health if on-site wastewater treatment plants use effluent for landscape irrigation or other reuse applications.

The existing rules state at R18-9-703.B.8(a)(ii) that reclamation systems that reuse industrial wastewater are subject to regulation under the reuse rules if industrial wastewater is "used for the production and processing of any crops or substance which may be used for human or animal food." ADEQ proposes to regulate the direct reuse of industrial wastewater under the APP program. ADEQ's basic position is that wastewater treatment plants at industrial facilities are categorical discharging facilities which require individual APPs. "Reclamation BADCT" will apply if industrial wastewater is treated and reused for agricultural irrigation, landscape irrigation, recreational or landscape impoundments, constructed wetlands or other reuse applications.

ADEQ Proposal: Repeal the existing reuse rules and integrate the current APP and reuse permit programs. Regulate all wastewater treatment plants under the APP program. Establish design criteria for reclaimed water distribution systems and require technical review. Regulate reuse sites under general APPs issued by rule.

3. **What is reclaimed water?**

"Reclaimed wastewater" is defined in the existing rules as "effluent which meets the standards for the specific reuses contained in R18-9-703" [See definition at A.A.C. R18-9-701.11 in Appendix 1]. "Effluent" is defined as "wastewater that has completed its passage through a wastewater treatment plant" [See A.A.C R18-9-701.2 in Appendix 1]. "Wastewater" is defined as "sanitary wastes of human origin, sewage, gray water, and industrial wastes that contain sanitary wastes...." [See A.A.C. R18-9-701.16 in Appendix 1].

ADEQ proposes to retain the basic concept that "reclaimed water" means wastewater that has completed its passage through a wastewater treatment plant. ADEQ proposes to define reclaimed water" as treated wastewater from a domestic, municipal or industrial wastewater treatment plant.

The proposed definition of "reclaimed water" will not include gray water. "Gray water" means wastewater from fixtures and water-using appliances other than toilets, dishwashers and kitchen sinks, including wastewater from bathroom sinks, tubs, showers and washing machines. Gray water is typically collected, treated and reused for residential landscape irrigation through the use of dual plumbing systems. Homes typically have separate gray water treatment and disposal systems which are separate from "black water" disposal systems that are connected to the community sewer

system. Gray water is not reclaimed water because it is not mixed with sanitary waste or "black water" and treated at a domestic, municipal or industrial wastewater treatment plant.

ADEQ proposal: "Reclaimed water" means wastewater that has passed through a domestic, municipal or industrial wastewater treatment plant. "Reclaimed water" does not include gray water.

4. **Does the definition of reclaimed water include contaminated ground water?**

The definition of reclaimed water does not include contaminated ground water. ADEQ recognizes that contaminated ground water may be treated as part of a remedial action and then reused. However, clean-up levels for contaminated ground water are established by rules governing Water Quality Revolving Assurance Fund projects or by federal regulations governing Superfund projects. The rules governing remedial action programs allow the consideration of reclaimed water quality criteria when establishing appropriate clean-up levels for contaminated ground water that is reused. For example, reclaimed water quality criteria may be considered an "applicable, relevant and appropriate requirement" [ARAR] under §121 of CERCLA if treated ground water is reused.

ADEQ Proposal: The definition of reclaimed water does not include contaminated groundwater.

5. **What is direct reuse of reclaimed water?**

The direct reuse of reclaimed water means that there is no discharge of reclaimed water to a navigable water or to an aquifer between the source wastewater treatment plant and the site of intended reuse. Direct reuse means that reclaimed water is conveyed through a pipeline or a canal from the source wastewater treatment plant to the reuse site.

The discharge of reclaimed water to a navigable water is regulated under the water quality standards program and the National Pollutant Discharge Elimination System (NPDES) permit program. For example, the discharge of reclaimed water into the Salt River channel or one of its tributaries to create an artificial lake or a constructed wetland would require an NPDES permit. The water quality standards that have been established for the Salt River would provide one of the bases for the development of discharge limitations in the NPDES permit.

The diversion and use of an effluent dominated water will not be regulated under the proposed revisions to the APP rules and "Reclamation BADCT" for two reasons. First, there is a statutory exemption from individual APP requirements for the application of water from any source, including wastewater, to grow agricultural

crops or for landscaping purposes, except as provided by A.R.S. §49-247 [See A.R.S. §49-250.B.15]. Second, regulation of this kind of indirect reuse under the APP program is unnecessary because the water quality standards program and the NPDES permit program adequately protect water quality for designated uses.

For example, the application of effluent dominated water that is diverted from the Gila River and used for agricultural irrigation in the Buckeye Irrigation District does not require an individual APP even though the water at the point of diversion may be 100% effluent. By contrast, the direct reuse of reclaimed water for agricultural irrigation in the Buckeye Irrigation District would be regulated under the APP program. That is, if reclaimed water was conveyed by a pipeline from the 91st Avenue Wastewater Treatment Plant to the Buckeye Irrigation District and used for agricultural irrigation, a general APP would apply.

Another form of indirect reuse occurs when reclaimed water is used to recharge ground water or when reclaimed water is stored underground for later recovery. The use of reclaimed water to recharge aquifers and the underground storage and recovery [USR] of reclaimed water require individual APPs [See A.R.S. §49-241.B.9]. Once reclaimed water is recharged or stored underground, ADEQ considers it to be ground water. The subsequent recovery and use of this ground water is not regulated under the APP program. Treatment requirements for ground water recharge and USR projects are driven primarily by compliance with aquifer water quality standards, not proposed reclaimed water quality criteria. In general, reclaimed water that is used for ground water recharge or that is stored underground must be treated to meet drinking water standards.

ADEQ Proposal: ADEQ will regulate the direct reuse of reclaimed water. Reclamation requirements will not apply to indirect reuse.

6. **How will wastewater treatment plants that supply reclaimed water for reuse be regulated?**

Under the existing rules, wastewater treatment plants that supply reclaimed water for reuse are regulated under reuse permits. The current rules prohibit a wastewater treatment plant from releasing reclaimed wastewater for reuse without a reuse permit from ADEQ [See A.A.C. R18-9-702.C in Appendix 1]. Also, the definition of a wastewater reclamation system in the existing rules includes both the wastewater treatment plant and the distribution system for the reclaimed water [See A.A.C. R18-9-701.17 in Appendix 1].

Wastewater treatment plants currently operate under a confusing and overlapping array of permits and notice requirements. These include: Notices of Disposal [NODs], Groundwater Quality Protection Permits (GWQPPs), Aquifer Protection Permits (APPs), reuse permits and National Pollutant Discharge Elimination System

(NPDES) permits. ADEQ proposes to consolidate some of these permit mechanisms under one regulatory "umbrella," the APP program [the proposed consolidation will not include NPDES permit requirements. The owner of a wastewater treatment plant that discharges to a navigable water will still need to obtain a NPDES permit].

The owner of a wastewater treatment plant that currently is operating under a NOD or GWQPP will be required to obtain an APP as ADEQ reduces the backlog of facilities on the APP priority list. Wastewater treatment plants that currently operate under reuse permits will be required to obtain APPs when their reuse permits expire [It should be noted that since the effective date of the APP rules, ADEQ has been requiring owners of wastewater treatment plants to obtain APPs].

In general, wastewater treatment plants with flows greater than or equal to 20,000 gpd are required to obtain an individual APP. Wastewater treatment plants with flows of less than 20,000 gpd that meet certain conditions prescribed in rule are regulated under a general APP [See A.A.C. R18-9-126]. ADEQ proposes to continue to regulate small wastewater treatment plants under general APPs [<20,000 gpd]. However, ADEQ will propose revisions to the general permit conditions for small wastewater treatment plants that are engaged in reclamation.

Under current state law, it is illegal to regulate a "reuse facility" under the APP program and the reuse permit program. This is because there is a statutory exemption at A.R.S. §49-250.B.8 which exempts "facilities which are defined and required to obtain a permit to reuse reclaimed wastewater" from APP requirements. ADEQ interprets this statutory exemption to be an either/or proposition. That is, a wastewater treatment plant may be regulated either as a categorical discharging facility under the APP program or as a "reuse facility" under a reuse permit program. A combined APP/reuse permit is not possible because the statutory exemption at A.R.S §49-250.B.8 makes these permit programs mutually exclusive.

ADEQ intends to eliminate confusion over how wastewater treatment plants are regulated by eliminating the reuse permit program in its entirety. The proposed repeal of the reuse permit program will render the statutory exemption at A.R.S. §49-250.B.8 meaningless because ADEQ will not define any facility as a "reuse facility" and no facility will be required to obtain a reuse permit. If the integration of the two permit programs is implemented, ADEQ will seek clean-up legislation to repeal §49-250.B.8.

The APP program is the most appropriate regulatory program for regulating wastewater treatment plants. First, this position is consistent with the apparent intent of the Legislature. Wastewater treatment plants are specifically listed as categorical discharging facilities in A.R.S. §49-241.B. The inclusion of wastewater

treatment plants in the list of categorical discharging facilities indicates a legislative intent to regulate such facilities under the APP program.

A wastewater treatment plant should not be defined as a "reuse facility" because, in most cases, a wastewater treatment plant will be engaged in a discharge activity which requires an individual APP. While a wastewater treatment plant may supply reclaimed water for reuse, it also may utilize reclaimed water for ground water recharge, store reclaimed water underground for later recovery, or discharge reclaimed water to a navigable water. Each of these activities requires an individual APP.

There are seasonal fluctuations in the demand for reclaimed water. Most reclaimed water is reused for agricultural irrigation or landscape irrigation. The seasonal demand for reclaimed water [high irrigation demand in the summer and the low irrigation demand in the winter], in combination with a relatively constant annual supply of reclaimed water, results in a surplus of reclaimed water during the winter months. In most cases, the available options for disposal or seasonal storage of the surplus reclaimed water [ground water recharge, USR or discharge to a navigable water] require an individual APP.

Since the majority of wastewater treatment plants are required to obtain individual APPs, it makes sense to consolidate the reuse permit and APP programs. This consolidation would implement the statutory mandate at A.R.S. §49-203.C to integrate water quality protection programs and to avoid duplication and dual permitting to the maximum extent practicable.

ADEQ also believes that wastewater treatment plants should be required to implement best available demonstrated control technology [BADCT]. BADCT implementation requires that wastewater treatment plants be designed, constructed and operated to ensure the greatest degree of discharge reduction achievable through the application of best available demonstrated control technology, processes, operating methods or other alternatives, including, where practicable, a technology permitting no discharge of pollutants [See A.R.S. §49-243.B.1]. ADEQ believes that the Legislature, by specifically listing wastewater treatment facilities as categorical discharging facilities in A.R.S. §49-241.B, intended that wastewater treatment plants employ the best available demonstrated pollution control technologies.

There are extensive statutory guidelines governing the BADCT determination for wastewater treatment plants [See A.R.S. §49-243]. State law requires ADEQ to take into account site-specific hydrologic and geologic characteristics; the opportunity for water conservation or augmentation; the economic impacts of the use of alternative technologies, processes or operating methods on an

industry-wide basis and other environmental factors when making the BADCT determination [See A.R.S. §49-243.B.1].

For existing facilities, the Director is required to consider the following factors:

1. The toxicity, concentrations and quantities of discharge likely to reach an aquifer from various types of control technologies;
2. The costs of the application of the technology in relation to the discharge reduction to be achieved from application of the technology;
3. The age of the equipment and facilities involved;
4. The industrial and control processes employed;
5. The engineering aspects of the application of various types of discharge control technologies;
6. Process changes;
7. Non-water quality environmental impacts, and
8. The extent to which water available for beneficial uses will be conserved by a particular discharge control technology.

For new facilities, the BADCT statute requires that wastewater treatment plants limit discharges of organic substances listed pursuant to 42 U.S.C. §241(b)(4) and 40 CFR §261.33(e), as well as any organic toxic pollutant that the Director determines will present a substantial threat to human health. Discharges of these toxic pollutants must be limited to the maximum extent practicable, regardless of cost [See A.R.S. §49-243.D].

ADEQ has developed a BADCT guidance document for municipal and domestic wastewater treatment plants. In this guidance document, ADEQ states that the BADCT determination for a wastewater treatment plant starts with a design that incorporates state-of-the-art discharge control technologies. The BADCT determination involves the selection of optimal treatment technologies at a wastewater treatment plant which will control discharges to an aquifer. The BADCT guidance document defines optimal treatment technologies in terms of performance standards. Table 1 on the following page summarizes the optimum reduction of pollutants through the application of best available demonstrated control technology.

"End of the pipe" compliance with the performance standards prescribed in Table 1 requires, at a minimum, the application of nitrogen removal, filtration and disinfection technologies. Therefore, the starting point for the BADCT determination for a new wastewater treatment plant is what is often called tertiary or advanced wastewater treatment.

Table 1. Optimum Reduction of Pollutants

Fecal coliform	2.2 CFU/100 ml [geometric mean]
Turbidity	1.0 NTU
Nitrogen	Below 10 mg/L as N
Flouride	4.0 mg/L*
Hazardous Substances with MCLs	Below MCLs
Hazardous Substances without MCLs	Action levels or concentrations representing 1 x 10^{-6} risk level, whichever is lower
A.R.S. §49-243.D pollutants	None detectable
Arsenic	0.05 mg/L*
Barium	1.0 mg/L*
Cadmium	0.010 mg/L* [0.005 mg/L**]
Chromium	0.05 mg/L* [0.01 mg/L**]
Lead	0.05 mg/L*
Mercury	0.002 mg/L*
Selenium	0.01 mg/L* [0.05 mg/L**]
Silver	0.05 mg/L* [MCL repealed**]
Methoxychlor	0.1 mg/L* [0.04 mg/L**]
2,4-D	0.1 mg/L* [0.07 mg/L**]
2,4,5-TP Silvex	0.01 mg/L* [0.05 mg/L**]
Trichloroethylene	0.005 mg/L*
Carbon tetrachloride	0.005 mg/L*

* Indicates a National Primary Drinking Water Maximum Contaminant Level [MCL].
** Indicates a recently revised MCL which has been adopted as an aquifer water quality standard since the publication of the BADCT guidance document.

It should be noted that new or revised aquifer water quality standards have been adopted for asbestos, nitrite, total nitrate and nitrite, benzene, o-dichlorobenzene, para-dichlorobenzene, 1,2-dichloroethane, 1,1-dichloroethylene, cis-1,2-dichloroethylene, trans-1,2-dichloroethylene, 1,2-dichloropropane, ethylbenzene, monochlorobenzene, styrene, tetrachloroethylene, toluene, 1,1,1-trichloroethane, vinyl chloride, xylenes, alachlor, atrazine, carbofuran, chlordane, DBCP, EDB, heptachlor, heptachlor epoxide, endrin, lindane, PCBs, toxaphene and radionuclides. These recently adopted aquifer water quality standards also represent performance standards which define BADCT. In 1993, ADEQ will propose the Phase III Aquifer Water Quality Standards to regulate 27 additional organic and inorganic chemicals.

There are three exceptions to the advanced wastewater treatment requirements described in the BADCT guidance document for a new wastewater treatment plant. A new wastewater treatment plant may meet BADCT requirements if the operator can demonstrate that: 1) the treatment plant is a zero discharge facility [i.e., there is no discharge to an aquifer]; or 2) 100% of the effluent from the facility is reused at consumptive rates; or 3) the treatment plant discharges to a navigable water that has an average annual flow of 5000 cfs or greater and the wastewater treatment plant is in compliance with a valid NPDES permit.

As noted above, advanced wastewater treatment is the starting point in the BADCT determination for a new wastewater treatment plant. However, the BADCT statute recognizes that there are alternatives to engineered treatment technologies. Land treatment can play an important role in the final BADCT determination. Site-specific hydrological or geological characteristics may be substituted for engineered treatment technologies to arrive at a final design or BADCT for a new treatment plant. Site-specific characteristics are a part of BADCT only to the extent that they control the quality of a discharge before it reaches an aquifer. If site-specific characteristics are to be used as part of the BADCT for a new wastewater treatment plant, the operator must provide data to ADEQ regarding the site-specific characteristics and must demonstrate the degree of discharge reduction that will be accomplished by them.

Obviously, the reuse of reclaimed water can play an important role in the BADCT determination for a new wastewater treatment plant. The site-specific hydrological or geological characteristics of reuse sites may substitute for advanced wastewater treatment technologies. For example, the optimum reduction of nitrogen is defined as less than 10 mg/L as N. "End-of-the-pipe" compliance with this performance standard requires installation of nitrogen removal technology at the wastewater treatment plant. However, the operator of a wastewater treatment plant may be able to demonstrate that total nitrogen uptake by plants or nitrogen transformations in the soil matrix at reuse sites permit the discharge of reclaimed water with total nitrogen concentrations in excess of 10 mg/L. The operator may demonstrate that nitrogen removal technology at the source wastewater treatment plant is unnecessary because the site-specific characteristics of reuse sites permit the discharge of total nitrogen in higher concentrations.

ADEQ will consider the site-specific characteristics of reuse sites in making the BADCT determination for a wastewater treatment plant that supplies reclaimed water for reuse. A wastewater treatment plant that supplies 100% of its reclaimed water for direct reuse may permit a level of treatment technology that is determined primarily by the proposed reclaimed water quality and treatment reliability requirements for reclamation. This is because the

BADCT guidance document for wastewater treatment plants states that the reuse of reclaimed water at consumptive rates is BADCT.

For example, if a wastewater treatment plant reuses 100% of its reclaimed water for agricultural irrigation of fiber, seed and forage crops at consumptive rates, the proposed "Reclamation BADCT" only requires secondary treatment and disinfection of the reclaimed water. If the wastewater treatment plant reuses 100% of its reclaimed water for reuse applications which include the landscape irrigation of parks and schoolgrounds, the proposed "Reclamation BADCT" requires advanced wastewater treatment [i.e., secondary treatment + coagulation/flocculation + filtration + disinfection].

ADEQ will propose that specific BADCT requirements be established for reclamation. "Reclamation BADCT" will prescribe the required treatment processes for various reuse applications and will include provisions to ensure treatment reliability. ADEQ proposes to revise the BADCT guidance document for municipal and domestic wastewater treatment plants to incorporate such reclamation requirements in this rulemaking.

ADEQ has considerable flexibility in making the BADCT determination for an existing wastewater treatment plant. Two key concepts articulated in the BADCT guidance document for domestic and municipal wastewater treatment plants are that BADCT is site-specific and that BADCT is negotiated. As noted earlier, A.R.S. §49-243 requires the consideration of many factors in making the BADCT determination for existing wastewater treatment plants. These factors include the potential for augmentation of the water supply, water conservation, the engineering and process change aspects of retrofitting a wastewater treatment plant and the cost of upgrading a facility in relation to the discharge reduction to be achieved. However, it should be noted that for existing wastewater treatment plants involved in reclamation, the proposed reclaimed water quality criteria and treatment reliability requirements for reclamation are <u>not</u> negotiable. Reclaimed water quality criteria and treatment reliability requirements are established to protect public health. These public health requirements cannot be compromised in BADCT negotiations for existing facilities.

ADEQ recognizes that current water resources planning in Maricopa and Pima Counties includes plans for the development of satellite wastewater treatment plants to supply reclaimed water for reuse. Under the ADEQ proposal, these satellite wastewater treatment plants will be required to obtain individual APPs and BADCT requirements will apply. However, if a satellite treatment plant supplies 100% of its reclaimed water for reuse at consumptive rates and disposes of surplus effluent to another wastewater treatment plant, the BADCT determination for the satellite plant will be driven primarily by the proposed reclaimed water quality criteria and treatment reliability requirements.

ADEQ recognizes that there may be concerns over the current administration of the APP program and the backlog of facilities that are on the APP priority list. There also may be questions over permit terms and modifications. APP permits are issued for the operational life of the facility [See A.A.C. R18-9-118]. Reuse permits are currently issued for five-year terms. ADEQ does not propose to change the term of the APP permit. However, issuing permits for the operational life of the facility raises the question of what should be done if the owner of wastewater treatment plant wants to begin supplying reclaimed water for reuse or wants to supply reclaimed water for a new reuse application that was not considered when the APP for the wastewater treatment plant was originally issued.

There are provisions in the APP rules which permit the modification of the permit [See A.A.C. R18-9-121.C]. The Director may modify an individual APP based upon a request from the permittee or on the Director's initiative. Requests for permit modification must be in writing and they must contain the facts and reasons which justify the request. For major modifications of an APP, certain public participation requirements must be met. Minor modifications to an APP may be made without public participation.

If an operator of a wastewater treatment plant seeks to modify an APP to supply reclaimed water for reuse, the change would be considered a major modification of the APP. If an operator of a wastewater treatment plant seeks to supply reclaimed for an additional reuse application with higher reclaimed water quality requirements, the change is a major modification. For example, if a wastewater treatment plant currently supplies reclaimed water for irrigation of non-food crops [which requires Class C reclaimed water] and the operator wants to begin supplying reclaimed water for irrigation of a local park [which requires Class A reclaimed water], the change would require a major modification of the APP. On the other hand, if the operator wants to supply reclaimed water for an additional reuse application which does not require higher quality reclaimed water, the change would only require a minor modification of the APP permit for the source wastewater treatment plant. ADEQ proposes to revise A.A.C. R18-9-121 to clarify these major and minor modifications to APPs.

ADEQ Proposal: All wastewater treatment plants will be required to operate under APPs. Small wastewater treatment plants [under 20,000 gpd] that meet eligibility criteria may operate under general APPs. ADEQ will consider reclaimed water quality criteria and treatment reliability requirements when making the BADCT determination for wastewater treatment plants that supply reclaimed water for reuse.

7. **How will treatment reliability be assured?**

There is a need for a high degree of treatment reliability in

wastewater treatment plants that supply reclaimed water for reuse. Treatment process reliability must be maintained because the failure of unit treatment processes can result in the delivery of improperly treated wastewater to reuse sites. Obviously, the delivery of inadequately treated wastewater for reuse is a public health hazard. Safeguards must be built into reclamation systems to prevent the delivery of untreated or inadequately treated reclaimed water in the event of a treatment system failure. Backup systems are particularly important for critical treatment processes [e.g., the disinfection system].

EPA has developed what are known as Class I reliability requirements. The EPA Class I reliability requirements provide for redundant wastewater treatment facilities to prevent treatment upsets during power and equipment failures, flooding, peak loads and maintenance shutdowns. EPA has identified the following design features as necessary for ensuring treatment reliability: Duplicate power sources; standby power for essential treatment plant elements; multiple or oversized units and equipment; emergency storage; flexibility of piping and pumping facilities to permit rerouting of flows under emergency conditions; and provision for emergency storage or disposal of sludge.

Non-design reliability features include provisions for qualified personnel; an effective monitoring program and an effective maintenance and process control program [See Appendix 3 for a summary of EPA Class I reliability requirements].

The Preliminary Draft EPA/U.S. Aid Water Reclamation Reuse Guidelines [October, 1991][hereafter "EPA Reuse Guidelines"] state that treatment reliability for wastewater treatment plants that are involved in reclamation should go beyond EPA Class I reliability requirements. The following treatment reliability factors should be considered:

1. Operator certification to ensure that qualified personnel are operating the water reclamation and reclaimed water distribution systems.
2. Instrumentation and control systems for on-line monitoring of treatment process performance and alarms for process malfunctions.
3. A quality assurance program to ensure accurate sampling and laboratory analysis protocol.
4. Adequate emergency storage to retain reclaimed water of unacceptable quality for retreatment or alternative disposal.
5. Seasonal storage to ensure that the quantity of reclaimed water is adequate to meet user demands.
6. A strict industrial pretreatment program and strong enforcement of sewer use ordinances to prevent the discharge of toxic pollutants to reclamation plants.
7. Monitoring of the reclaimed water distribution system to ensure that reclaimed water quality is maintained.

The EPA Reuse Guidelines include the following discussion on treatment reliability:

a. Power Supply

The operation of wastewater treatments is dependent upon electric power. Treatment may be significantly impaired by power outages lasting more than 1 hour. Also, wastewater overflows may occur from pumping stations and upstream sewers, creating a public health hazard. Therefore, a standby power source should be provided at all reclamation plants, except those few that operate entirely by gravity and which have no critical treatment processes relying on electric power. The standby power source should be of sufficient capacity to provide necessary service during the failure of the normal power supply. Standby power may include gasoline or diesel fuel operated generators or connections to a completely separate power system.

b. Multiple units and equipment

When treatment process units are taken out of service for maintenance, repair or because of breakdowns, alternate units should be available to continue treatment of wastewater. Multiple units or standby unit processes are reliablity features which provide the ability to continue appropriate treatment while treatment process units are out of service.

Multiple units means two or more treatment process units which operate in parallel. A standby unit treatment process means a completely separate unit process which is maintained in operable condition and is capable of successfully replacing the system that operates normally. For example, a wastewater treatment plant may have a separate filtration system on "standby."

Reclamation plants should provide redundancy either through multiple unit treatment processes or standby units, at least for major unit treatment processes. In the alternative, reclamation plants can provide for emergency storage or disposal. For example:

1. Alarms, short-term retention or disposal provisions and standby replacement equipment;
2. Alarm and long-term storage or disposal provisions;
3. Automatically actuated long-term storage or disposal provisions.

c. Piping and pumping flexibility

The design of process piping, equipment arrangement and unit treatment structures should provide maximum flexibility of operation. Pipelines and pumps should not be installed that would bypass treatment processes and allow inadequately treated reclaimed water to enter the reclaimed water distribution system.

d. Emergency storage or disposal

A wastewater treatment plant should be designed to contain or provide alternative treatment and disposal of reclaimed water whenever the treated wastewater does not meet prescribed reclaimed water quality criteria. Emergency storage and disposal differs from seasonal storage and operational storage of reclaimed water. Emergency storage and disposal provisions may include holding ponds or tanks, evaporation ponds or spray disposal areas; discharge to a navigable water or pumping to another wastewater treatment plant.

Where emergency storage is to be utilized as a treatment reliability feature, storage capacity is an important consideration. Emergency storage requirements depend, in part, on the volume of operational storage available in the distribution system. Short-term retention capacity of reclaimed water in holding facilities for 24 hours is often provided in reclamation systems relying on a single power source. This short-term emergency storage is suitable for situations where reserve parts and replacements are immediately available and corrective actions will take no longer than 24 hours. Where this is not the case, emergency storage capacity should be 20 days or longer for effective treatment plant reliability.

e. Disinfection

Provisions for adequate and reliable disinfection of reclaimed water are essential. The most widely used disinfection process is chlorine disinfection. Chlorine disinfection processes may be interrupted because of chlorinator failure, exhaustion of the chlorine supplies or power failure. A variety of reliability features can be implemented to assure adequate disinfection. These include: standby chlorine cylinders; chlorine cylinder scales; manifold systems; alarm systems; automatic cylinder changeover; standby chlorinators; multiple-point chlorination; automatic control of chlorine dosage; and automatic measuring and recording of chlorine residuals.

f. Alarms

Alarm devices should be required for critical treatment processes to provide warning of loss of power from normal power supplies or failure of any unit treatment process. Automatic alarm devices are a necessity at all reclamation facilities, especially at wastewater treatment plants where no employees are stationed full-time. If a critical treatment process fails, the condition may go unnoticed for an extended time period and inadequately treated wastewater may enter the distribution system.

A minimum system would consist of alarms at critical treatment units to alert an operator of a malfunction. A reclamation plant should have a full-time operator or an operator who is on call

whenever the reclamation plant is in operation. In the latter case, automatically actuated emergency control mechanisms should be installed and maintained at the reclamation plant to divert inadequately treated wastewater to emergency storage.

Along with the alarm system, there must be means available to take corrective action. Provisions must be made to provide alternative treatment, storage or disposal of wastewater until corrective action can be taken. For example, an alarm may trigger an automatic diversion mechanism which discharges wastewater to emergency storage or disposal.

g. Operator training and competence

Qualified, well-trained operators are essential to ensure that the reclaimed water that is produced at a wastewater treatment plant is of acceptable quality. The operator is believed to be the most critical reliability factor in the wastewater treatment system. There are three factors related to operators that affect treatment reliability: attendance at the facility, competence and training.

The need for operator attendance at the wastewater treatment plant is dependent upon the size and complexity of the plant, type of reuse, degree of automation, alarm systems in place and the reliability features that have been incorporated into the plant design. A full-time operator is recommended for wastewater treatment plants which provide reclaimed water for urban reuse applications. Operator certification should be required to assure operator competence. Operators of reclamation facilities should hold a Grade IV certification from the State of Arizona.

h. Proposed reliability requirements

The State of California wastewater reclamation regulations contain both design and operational requirements necessary to ensure a minimum level of treatment reliability. Articles 8, 9 and 10 of the California reclamation criteria require operator certification, preventive maintenance, operational recordkeeping procedures, bypass prohibitions, alarm requirements for unit treatment process failure, redundancy of treatment units, short-term and long-term storage and disposal provisions, standby replacement equipment and standby power source requirements. ADEQ proposes to revise the BADCT guidance document to incorporate the California treatment reliability requirements for wastewater treatment plants that supply reclaimed water for reuse.

ADEQ Proposal: ADEQ proposes to adopt the treatment reliability requirements in the California reclamation criteria. ADEQ will revise the BADCT guidance document to address treatment reliability

8. **How will reclaimed water distribution systems be regulated?**

Reclaimed water distribution systems must have stringent design and operational safeguards to protect public health. The major public health concern which guides the design, construction and operation of a reclaimed water distribution system is the prevention of cross-connections to potable water distribution systems. Other reclaimed water distribution system issues of concern include:

1. The development of a uniform system to identify components of the reclaimed water distribution system and distinguish them from components of the potable water supply system;
2. Provision for routine monitoring and inspection of reclaimed water distribution systems to ensure safe operation;
3. The establishment of adequate separation criteria between reclaimed water distribution system pipelines and potable water supply pipelines;
4. Backflow prevention at potable water service connections for reuse sites with dual distribution systems;
5. Maintenance of an adequate chlorine residual within the distribution system to maintain the microbiological quality of the reclaimed water;
6. Operational and seasonal storage; and
7. Adequate plan and field review of reclaimed water distribution systems.

In general, ADEQ proposes to rely on existing technical review requirements to regulate reclaimed water distribution systems. The owner of a new reclaimed water distribution system will be required to submit design plans for the system to ADEQ or to a local regulatory authority that has been delegated authority to conduct technical review and obtain an Approval to Construct the system. This technical review requirement also will apply to any extensions or modifications of an existing reclaimed water distribution system. ADEQ proposes to promulgate reclaimed water distribution system design criteria in revised Sewage System rules.

Once a reclaimed water distribution system is constructed, the owner of the reclaimed water distribution system will be required to obtain an Final Approval of Construction before deliveries of reclaimed water to reuse sites may begin. Field inspection of the reclaimed water distribution system or the submittal of "as-built" plans by a registered professional engineer and a cross-connection control test will be required before a Final Approval of Construction will be granted.

ADEQ recognizes that canals may be used as part of a reclaimed water distribution system. Concrete-lined irrigation canals that are used to transport reclaimed water currently are regulated by a general APP [See A.A.C. R18-9-129.H]. ADEQ will require that all canals which carry reclaimed water for reuse applications be concrete-lined or have approved synthetic liners.

ADEQ proposes to adopt design criteria for reclaimed water distribution systems that are based upon the draft "Guidelines for Distribution of Nonpotable Water" published by the California-Nevada Section of the American Water Works Association [1991][Hereater referred to as "AWWA Guidelines"]. The AWWA Guidelines provide specific guidance for the design, construction and operation of reclaimed water distribution systems. The AWWA Guidelines address reclaimed water transmission and distribution pipelines, seasonal and operational storage, pumping, on-site applications and system managment.

ADEQ proposes to adopt the following sections of the AWWA Guidelines, as modified, as design criteria for reclaimed water distribution systems:

§2.1 System Pressure: In general, ADEQ will not regulate reclaimed water distribution system pressure. However, reclaimed water distribution systems must be designed to maintain a minimum system pressure at the reuse site during the peak demand hour.

If a reclaimed water distribution system is operated at low pressure, the operator of the system may have to set requirements for end users to install only low pressure irrigation devices at reuse sites. Owners of reuse sites with reuse applications which require higher pressures [e.g., spray irrigation on golf courses] may need to install on-site booster stations. Booster stations may be installed and operated by end users or by the operator of the reclaimed water distribution system.

ADEQ will propose one system pressure requirement. The Guidelines recommend that reclaimed water distribution systems be operated at system pressures that are lower than potable water supply systems to mitigate cross connections. The AWWA recommends that a pressure differential of 10 psi or greater be maintained between the reclaimed water and potable water distribution systems with the potable water system having the higher pressure.

§2.2 Minimum depth: ADEQ proposes to require that the top of the reclaimed water distribution system pipelines be a minimum of 36 inches below the finished street grade.

§2.3 Minimum separation: ADEQ proposes to modify the AWWA Guidelines recommendations so that they are consistent with the separation criteria currently prescribed in the Sewage System rules at A.A.C. R18-9-811. Reclaimed water distribution system pipelines that are parallel to potable water supply system pipelines shall be installed at least six feet horizontally and two feet lower than potable water supply system pipelines. Reclaimed water distribution system pipelines shall cross a minimum of two feet below potable water pipelines. Reclaimed water distribution system pipelines shall be located so that they cross above sewer mains.

Common trench construction for potable water supply sytem pipelines and reclaimed water distribution system pipelines is prohibited.

ADEQ recognizes that it may not always be possible to maintain the prescribed horizontal and vertical separations between the potable water, reclaimed water distribution system pipelines and sewer mains. In such cases, a variance from the minimum separation criteria may be obtained provided special construction requirements are met. Special construction requirements may include: 1) constructing the reclaimed water pipeline with mechanical joint ductile iron pipe or with slip-joint ductile iron pipe if joint restraint is provided; or 2) encasing the potable water and reclaimed water pipelines in at least six inches of concrete [See A.A.C R18-9-811.A]. Alternate construction techniques, materials and joints may be authorized on a case-by-case basis. Under no circumstances should a potable water line come within two feet of either side of a reclaimed water pipeline or cross below a reclaimed water pipeline.

§2.4 Reclaimed water distribution system pipeline identification

ADEQ proposes to require that all components of reclaimed water distribution systems be clearly identified to prevent cross connections. ADEQ proposes to adopt a standardized color coding and marking system for reclaimed water pipelines and devices in revised Sewage System rules.

All new buried transmission/distribution piping in the reclaimed water distribution system, including service lines, valves and other appurtenances shall either be colored purple [Panatone 522C], and embossed or integrally stamped/marked CAUTION; NONPOTABLE WATER - DO NOT DRINK, or CAUTION: RECLAIMED WATER - DO NOT DRINK, or be installed with a purple identification tape or a purple polyethylene vinyl wrap [Panatone 512C].

§2.4.2 Identification tape: Identification tape shall be prepared with white or black printing on a purple field, color Panatone 512C, having the words: CAUTION: NONPOTABLE WATER - DO NOT DRINK or CAUTION: RECLAIMED WATER - DO NOT DRINK. The overall width of the identification tape shall be at least three inches in width. Identification tape shall be installed on the top of the reclaimed water distribution system pipelines longitudinally and shall be centered. The identification shall be continuous in the coverage of the pipe and shall be fastened to each pipe length no more than ten feet apart. Identification tape differentiating the reclaimed water distribution system pipelines from other utility lines shall be consistent throughout the service area.

Pipe locating tape: The AWWA Guidelines do not address the use of detectable pipe locating tape. However the Maricopa Association of Governments [MAG] has promulgated Uniform Standard Specifications and Details for pipe locating tape. ADEQ recommends

that a revised version of the MAG specifications be adopted for statewide use:

Detectable pipe locating tape shall be a minimum of 4.0 mils thick, inert polyethylene plastic that is impervious to all known alkalis, acids, chemical reagents and solvents likely to be encountered in soil, with a minimum 1/3 mil thick metallic foil or two embedded copper wires. The tape shall be a minimum of three inches in width. Locating tape shall be purple in color and printed in the same manner as pipeline identification tape.

Detectable pipe locating tape shall be installed over all reclaimed water pipelines. Locating tape shall be buried at least 18 inches below the surface over the center of the pipe. Backfill shall be sufficiently leveled so that the tape is installed on a flat surface. The tape shall be centered in the trench with the printed side up. Care shall be exercised to avoid displacement of the tape and to ensure its integrity.

§2.5 Above-ground components: The AWWA Guidelines prescribe identification requirements for above-ground components of reclaimed water distribution systems. § 2.5.1 and § 2.5.2 of the Guidelines require that all above-ground components be clearly identified and consistently color-coded [purple, Panatone 512C] to differentiate the reclaimed water distribution system from the potable water supply system. The AWWA Guidelines recommend that valve boxes be the standard concrete or fiberglass boxes with special triangular covers. Valve covers for reclaimed water distribution system pipelines should not be interchangeable with valve covers for the potable water supply system and they should have a recognizable inscription cast on the top surface which identifies them as part of the reclaimed water distribution system.

§ 2.6 Blow off assemblies: Residual organics and bacteria may grow in the dead spots in a reclaimed water distribution system, leading to nuisance odors and clogging problems. Blow-off valves should be installed in reclaimed water distribution pipelines to remove reclaimed water and sediment. ADEQ proposes to require the installment of in-line or end-of-line type blow off assemblies or drain assemblies. The line tap for a blow off assembly should be no closer than 18 inches to a valve, coupling, joint or fitting unless it is an end-of-line type assembly. Again, blow off valves should be purple in color and marked to identify them as part of the reclaimed water distribution system.

§3.1 Seasonal storage: In general, seasonal storage is necessary for one of the following reasons: 1) to store reclaimed water during periods of low demand for subsequent use during peak demand periods; or 2) to avoid discharge of reclaimed water to a navigable water. Seasonal storage may be in open reservoirs or underground.

The quality of reclaimed water that is stored in open reservoirs will degrade over time. Regrowth of bacteria and the growth of algae may create aesthetic and operational problems when the reclaimed water is retrieved from storage and used. The reclaimed water may not meet water quality requirements for intended reuse applications. Reclaimed water that is recovered from storage in open reservoirs may need to be refiltered and chlorinated before entry into the distribution system.

The AWWA Guidelines recognize that algal growth and suspended solids in reclaimed water that has been stored in open reservoirs are sources of particles that may clog irrigation sprinkler systems. Most sprinkler system control valves and sprinkler heads can pass particles which go through a 30-mesh screen. This corresponds to a screen opening of 0.0233 inch or 600 microns. The AWWA Guidelines recommend that all irrigation water that enters a reclaimed water distribution system from an open reservoir be filtered or screened through a micro strainer with a 200-mesh screen.

§3.2 Operational storage: The purpose of operational storage of reclaimed water is to accomodate diurnal fluctuations in the supply of and demand for reclaimed water. The size of operational storage facilities depends primarily on the nature of user demand. Operational storage may be provided at the source wastewater treatment plant, in the distribution system or at reuse sites. In general, operational storage is provided in covered storage tanks or in open ponds. Open ponds typically are used to provide operational storage at the reuse site [e.g., golf course ponds]. Covered storage may be used where land for open storage reservoirs is unavailable and where aesthetic considerations are more important [e.g., urban reuse applications]. As a general rule, operational storage facilities should be sized to handle at least 1½ to 2 times the average peak demand flow.

Open storage reservoirs which are not intended for use as landscape or recreational impoundments should be within a fenced area to restrict public access. The reclaimed water storage facility should be identified with signs containing the following warning: "WARNING: RECLAIMED WATER - DO NOT DRINK" or "CAUTION: NONPOTABLE WATER - DO NOT DRINK" in English and in Spanish. Signs should be posted on the surrounding fence and at the entrance to the storage facility.

§4 Pumping: Pumping facilities for reclaimed water distribution systems shall be clearly identified to differentiate them from potable water supply pumping facilities. All exposed and above ground piping, fittings, pumps, valves etc. shall be purple in color. In addition, all piping should be identified with appropriate warning labels reading "CAUTION: RECLAIMED WATER - DO NOT DRINK" or "CAUTION: NONPOTABLE WATER - DO NOT DRINK."

The AWWA Guidelines recommend that pump station areas be fenced and that at least one warning sign be posted on the fence where it can be readily seen by all personnel entering the facility. If potable water is used as seal water for reclaimed water pump seals, the potable water supply must be adequately protected with a backflow prevention device. Owners of reclaimed water distribution systems must provide adequate control of any release of reclaimed water from the pump station area and proper drainage of packing seal water. Finally, all reclaimed water pumping systems must have proper surge protection to prevent the loss of reclaimed water through broken transmission lines resulting from water hammer and pressure surges.

Chlorine residual: The maintenance of an adequate chlorine residual in the reclaimed water distribution system is an important public health requirement. It is necessary to maintain the microbiological quality of reclaimed water and prevent the regrowth of bacteria in the distribution system. The owner of a reclaimed water distribution system should be required to maintain an adequate free chlorine residual in the distribution system. ADEQ proposes to establish a 2 mg/L free chlorine residual requirement for reclaimed water distribution systems.

Modification or extension of reclaimed water distribution system: Any modification or extension of a reclaimed water distribution system will require an Approval to Construct and a Final Approval of Construction. Additional dye testing for cross-connection control may be required by ADEQ or delegated local regulatory authorities.

Flow recording: Accurate flow recording data is essential to the efficient management of a reclaimed water distribution system. Information on the flow of reclaimed water is important in the determination of the size of seasonal and operational storage facilities necessary to balance supply and demand. Accurate flow monitoring data also can be used to document the overapplication of reclaimed water at reuse sites. ADEQ proposes to require meters at reuse sites to monitor the amount of reclaimed water that is delivered. Operators of reclaimed water distribution systems will be required to maintain accurate records of the amount of reclaimed water that is delivered to reuse sites.

Future expansion: Design plans for reclaimed water distribution systems should "anticipate and provide for future sewage treatment needs" [See A.R.S. §49-104.B.13(c)]. Reclaimed water distribution systems should be designed to allow for future expansion. Turnouts should be installed at points in the distribution system where future connections are projected. Pipelines, pump stations and other major components of reclaimed water distribution systems should be sized to permit future growth.

8. **How will reuse sites be regulated?**

Examples of reuse sites include farms and turf areas that are irrigated with reclaimed water (e.g., fields, pastures, orchards, vineyards, golf courses, parks, schoolgrounds, cemeteries, highway medians and landscapes, common areas, etc.). Other examples of reuse sites include recreational and landscape impoundments that are filled with reclaimed water and constructed wetlands which utilize reclaimed water.

ADEQ will propose that general APPs be issued for agricultural irrigation, landscape irrigation and for impoundments of reclaimed water. APP general permit conditions may address reclaimed water quality requirements; technical review requirements; backflow prevention, cross-connection control; public notification and access restrictions; ponding, overspray and runoff control and impoundment design. ADEQ Field Services staff will inspect reuse sites periodically to monitor compliance with general APP permit conditions.

Adequate plan and field review of reuse site irrigation systems followed by periodic inspections are necessary to ensure that the the irrigation systems at reuse sites operate safely. In general, the owner of the reuse site will be required to submit design plans for an irrigation system and impoundments to ADEQ or to a local county health department that has been delegated authority to conduct technical review. The owner of the reuse site will be required to obtain an Approval to Construct the irrigation system or the impoundment. Any extension or modification of the reuse site irrigation system must be approved by ADEQ or the county health department.

Once a reuse site irrigation system or an impoundment is constructed, the owner will be required to obtain a Final Approval of Construction before irrigation with reclaimed water may begin or an impoundment may be filled with reclaimed water. ADEQ field review of the reuse site or submittal of as-built plans by a professional engineer will be required before a Final Approval of Construction will be granted. Field review will involve the on-site inspection of the irrigation system and any impoundments to determine if they have been built in conformity with approved plans and specifications or submittal of as-built plans by a registered professional engineer. A cross-connection control test will be required if there is a potable water supply distribution system at the reuse site. Finally, an on-site irrigation system test will be required to ensure that overspray, ponding and runoff are not occurring at the site.

ADEQ proposes to promulgate irrigation system and impoundment criteria in revised Sewage System rules and in general APPs. Design criteria and specifications for reuse site irrigation systems and

impoundments will be prescribed to guide technical review. ADEQ will prescribe reclaimed water quality and operational requirements as permit conditions in general APPs for agricultural irrigation, landscape irrigation and impoundments.

§5.1 Strainers at meter/point of connection: The AWWA Guidelines state that water strainers may be required at reuse sites before meters or other mechanical devices such as pressure-reducing valves because of suspended solids in reclaimed water. Strainers are of various types and can range in mesh size from 20 to 325. A mesh of 20 to 80 is normally adequate. In order to reduce maintenance, suspended solids that will not plug on-site irrigation nozzles should normally be allowed to pass.

§5.2 Controllers: Irrigation with reclaimed water often is scheduled at night to limit public exposure to reclaimed water and to increase irrigation efficiency. Automatic controllers are often used at the reuse site to automatically open and close irrigation system valves. If automatic controllers are used, the following requirements should apply:

1. Controllers shall be fully automatic.
2. Controllers shall have multiple starting times that can be selected for any time of day, seven days a week, and should be equipped with moisture sensors to avoid activation when it is raining or the soil is saturated.
3. A drawing of the area served by the controller shall be sealed in a plastic cover and placed in the controller box.
4. Controllers of reclaimed water shall be color-coded to differentiate the reclaimed water system from the potable water supply system. Controllers shall be labeled inside and outside, warning that the system utilizes reclaimed water.
5. The controller box shall be keyed to allow access only by authorized personnel.

§5.3 Backflow prevention: Backflow prevention devices are not normally used on reclaimed water distribution systems. However, backflow prevention devices must be installed when potable water and reclaimed water are delivered to the same reuse site. In such cases, a backflow prevention device is required at the potable water supply service connection. The backflow prevention device should be either an approved air gap or reduced pressure principle backflow prevention device [See backflow prevention requirements in the public water supply system rules at A.A.C. R18-4-232]. The backflow prevention assembly at the potable water supply service connection should be tested upon installation and annually thereafter.

§5.4 System identification: All components of the reclaimed water irrigation system at the reuse site must be identified to differentiate them from the potable water supply system. Pipelines

and appurtenances should be purple in color [Panatone 522C] or wrapped with purple identification tape [Panatone 512C].

Conversion of potable water supply system lines to the reclaimed water distribution system: In some cases, potable water supply pipelines may be taken out of service and converted for use as part of a reclaimed water distribution system. Where conversion of an in-place potable water supply system to reclaimed water is planned, all connections to the potable water supply system must be accurately located and severed to prevent cross connections. Dye testing for cross-connection control will be required of all converted systems upon completion of the conversion. ADEQ will require that all exposed subsurface piping and fixtures be appropriately identified as part of the reclaimed water distribution system during the conversion.

§5.5.1 Hose bibbs and fittings: Reclaimed water irrigation system must be designed to prevent unintended connections. All fittings on the reclaimed water distribution system should be designed to prevent interconnections between the potable water supply system and the reclaimed water irrigation system. The AWWA Guidelines recommend that hose bibs be prohibited on reclaimed water irrigation systems. ADEQ proposes to require that above-ground hose bibbs on reclaimed water distribution systems either be secured to prevent public access or that quick coupling devices be used.

§5.7 Drinking fountains and public facilities: Drinking water fountains, grills and picnic tables shall not be placed in areas that are irrigated with reclaimed water. Exterior drinking fountains and picnic areas must be shown and called out in design plans. The overspraying of any outside area where food is prepared or eaten is prohibited. In general, food establishments and eating areas should not be located in areas that are irrigated with reclaimed water.

Ponding, overspray and runoff: Reuse site irrigation systems should be designed and operated to minimize ponding and runoff of reclaimed water. Reuse site irrigation systems shall use part-circle sprinklers along boundaries, sidewalks and roadways to prevent overspray of hard surface areas and runoff. ADEQ proposes to require an on-site irrigation system test before irrigation with reclaimed water is permitted. The irrigation system test will require activation of the irrigation system and inspection of the reuse site for ponding, runoff or over-spraying on unintended use areas. Excessive ponding or runoff at the reuse site may require adjustment of irrigation rates or the duration of irrigation, changes in types of sprinkler nozzle heads or the location of sprinkler heads.

Restrictions on time of irrigation: In general, irrigation should be scheduled at times to minimize the opportunity for public

contact with reclaimed water. For example, irrigation of golf courses should be scheduled at night with a maximum amount of drying time before public use.

Public notification: All reuse sites that are irrigated with reclaimed water shall display signs reading: "IRRIGATED WITH RECLAIMED WATER - DO NOT DRINK FROM IRRIGATION SYSTEM" or similar warnings. ADEQ proposes to require that these warning signs be printed in English and in Spanish. Where reclaimed water is used for landscape and recreational impoundments, warning signs shall be installed to notify the public that reclaimed water is being used and that swimming is prohibited. Golf courses that are irrigated with reclaimed water shall include notices on score cards which provide warnings similar to those described above. ADEQ proposes to require owners of reuse sites to give annual public notice to owners of adjacent residential properties that reclaimed water is used for irrigation.

Additional treatment at the reuse site: An owner of a reuse site may accept reclaimed water and provide additional treatment at a reuse site in order to comply with reclaimed water quality criteria. In such cases, the wastewater treatment plant at the reuse site which provides the additional treatment will require an individual APP.

9. **How will ground water recharge projects be regulated?**

Ground water recharge projects are specifically identified in A.R.S. §49-241.B as categorical discharging facilities that are regulated under the APP program. An individual APP is required for ground water recharge with reclaimed water. Treatment requirements for ground water recharge projects are driven primarily by compliance with aquifer water quality standards. Reclamation criteria will not apply to ground water recharge projects.

10. **How will the underground storage and recovery of reclaimed water be regulated?**

Underground storage and recovery projects are specifically identified in A.R.S. §49-241.B as categorical discharging facilities that are regulated under the APP program. The underground storage of reclaimed water requires an individual APP. Again, treatment requirements for underground storage and recovery projects are driven primarily by compliance with aquifer water quality standards. The subsequent recovery and use of reclaimed water that has been stored underground will not be regulated by ADEQ.

11. **How will canals that carry reclaimed water be regulated?**

There is a general aquifer protection permit for canals that carry effluent provided that: 1) the effluent is added for the purpose

of delivery to a reuse, recharge or underground storage and recovery facility that has a permit; 2) the canal is concrete-lined; 3) the effluent does not exceed aquifer water quality standards [except turbidity and bacteria] and 4) the volume and rates of effluent added do not exceed that necessary to meet the requirements of the permitted reuse, recharge, or underground storage and recovery facility [See A.A.C. R18-9-129.H]. ADEQ proposes to continue to regulate canals under this general permit.

It should be noted that certain canals are listed as navigable waters in Appendix B of the water quality standards rules found at Title 18, Chapter 11 of the Arizona Administrative Code. The discharge of reclaimed water to a canal that is listed in Appendix B of the water quality standards rules requires an NPDES permit.

ADEQ Proposal: Canals that transport reclaimed water are regulated under a general APP. Canals that are listed as navigable waters are regulated under the water quality standards program and NPDES permit programs.

B. REUSE STANDARDS

1. How will reclaimed water quality be regulated?

The primary consideration in the regulation of reclamation systems is that the quality of the reclaimed water be appropriate for its intended use. The most important water quality objective is that reclaimed water be adequately disinfected to protect public health. Also, for many urban reuse applications, reclaimed water must be clear, odorless and colorless to ensure that is aesthetically acceptable to the public.

ADEQ proposes the establishment of three classes of reclaimed water quality criteria for various reuse applications. The proposed reclaimed water quality criteria are technology-based. For reuse applications where there a risk of ingestion of reclaimed water, contamination of food crops or where there is unrestricted public access to the reuse site, ADEQ proposes that wastewater receive secondary treatment + coagulation/ flocculation + filtration + disinfection. For reuse applications where there is a significant but relatively lower risk of human exposure to reclaimed water [e.g., restricted access landscape irrigation, recreational impoundments where swimming is prohibited and landscape impoundments] ADEQ proposes that wastewater receive secondary treatment + filtration + disinfection. For reuse applications where the risk of human exposure to reclaimed water is minimal, ADEQ proposes that wastewater receive secondary treatment + disinfection [e.g., irrigation of nonfood crops, constructed wetlands].

2. What reuse applications are recognized by the existing rules and does ADEQ propose to amend or eliminate any of them in this rulemaking?

Existing reuse applications include the use of reclaimed water for the irrigation of orchards; irrigation of fiber, seed and forage crops; irrigation of pastures; irrigation of food crops that are eaten raw and food crops that undergo additional processing; livestock watering; landscape irrigation (open access and restricted access); creation of artificial wetlands; industrial reuse applications and impoundments where full body contact and incidental human contact may occur. The direct potable reuse of reclaimed water is prohibited [See Table I and A.A.C. R18-9-702.M in Appendix 1].

ADEQ proposes to retain all of the above-described reuse applications except irrigation of food crops that receive additional processing. ADEQ is proposing a single reclaimed water quality criterion for irrigation of all food crops. In addition, ADEQ proposes to recognize several new reuse applications including the reuse of reclaimed water for dust control and toilet flushing.

ADEQ proposes to retain the current prohibition against direct potable reuse. While ADEQ recognizes that promising research has been conducted nationally on the feasibility of closed-loop, direct potable reuse systems, ADEQ believes that the prohibition against direct potable reuse should be retained for the following reasons:

1. Additional research on the public health effects of using reclaimed water in closed loop, direct potable reuse systems needs to be done, especially on the fate of trace organic chemicals in reclaimed water.
2. The level of treatment reliability needed in closed loop systems needs to be defined.
3. At the present time, there is no demonstrated need for direct potable reuse systems. Instead, the reuse of reclaimed water for nonpotable uses should be encouraged.
4. The public is not ready to accept direct potable reuse.
5. Direct potable reuse is not currently practiced anywhere in the world.

3. **What are the existing reclaimed water quality criteria for reuse applications?**

A.A.C. R18-9-703 and Tables I - IV in the existing rules prescribe numeric, reclaimed water quality criteria and monitoring requirements for specific reuse applications. In general, the existing rules prescribe allowable limits for fecal coliform, enteric viruses and parasites, turbidity and pH [See "Table I - Allowable Permit Limits for Specific Reuses" in Appendix 1]. Reclaimed water that is used for agricultural irrigation, livestock watering and recreation also must meet surface water quality standards for trace substances, organic chemicals, toxic substances and radiochemicals [See A.A.C. R18-9-703.A in Appendix 1].

The existing rules use the concentration of fecal coliform organisms as an indicator of the microbiological quality of reclaimed water. Fecal coliform criteria are expressed as 5-sample geometric mean concentrations and single sample maximum concentrations.

The microbiological criteria for existing reuse applications are:

Irrigation of food crops consumed raw	2.2 cfu/100 ml [5-sample geometric mean] 25 cfu/100 ml [single sample maximum]
Open access landscape irrigation	25 cfu/100 ml [5-sample geometric mean] 75 cfu/100 ml [single sample maximum]

Impoundments [full body contact]	200 cfu/100 ml [5-sample geometric mean] 800 cfu/100 ml [single sample maximum]
Restricted access landscape irrigation	200 cfu/100 ml [5-sample geometric mean] 1000 cfu/100 ml [single sample maximum]
Other reuse applications	1000 cfu/100 ml [5-sample geometric mean] 4000 cfu/100 ml [single sample maximum]

The existing rules also prescribe stringent reclaimed water quality criteria for enteric viruses. Enteric virus criteria apply to the reuse of reclaimed water for irrigation of food crops that are consumed raw and for recreational impoundments where full body contact takes place [1 plaque forming unit, a most probable number of 1 or 1 immunoflourescent foci per 40 liters]. Less stringent enteric virus criteria apply to the reuse of reclaimed water for open access landscape irrigation and for recreational impoundments where incidental human contact takes place [125 enteric virus units per 40 liters]. The existing rules prescribe enteric virus criteria but reuse permittees are not required to monitor routinely for enteric viruses [See R18-9-703.B in Appendix 1].

There are reclaimed water quality criteria for parasites including Entamoeba histolytica, Giardia lamblia, Ascaris lumbricoides and the common large tapeworm. The applicable criterion for parasites is "none detectable." Reclaimed water quality criteria for parasites apply to the use of reclaimed water for recreational impoundments, irrigation of food crops that are consumed raw, irrigation of pastures, livestock watering and open access landscape irrigation [See Table I in Appendix 1]. Again, the existing rules prescribe reclaimed water quality criteria for parasites but reuse permittees are not required to monitor routinely for them [See R18-9-703.B in Appendix 1].

Concentrations of trace substances, organic chemicals, toxic substances and radiochemicals in reclaimed water must meet surface water quality standards when the reclaimed water is used for agricultural irrigation, livestock watering and recreational purposes [See A.A.C. R18-9-703.A in Appendix 1]. However, like enteric viruses and parasites, reuse permittees are not required to monitor routinely for these pollutants [See R18-9-703.B in Appendix 1].

The existing rules prescribe reclaimed water quality criteria and monitoring requirements for surface irrigation with on-site wastewater treatment plant effluent and gray water. The existing

fecal coliform criteria are 25 cfu/100 ml [5-sample geometric mean] and a single sample maximum concentration of 75 cfu/100 ml. Monitoring requirements are minimal. A reuse permittee must take 5 samples in one calendar month at least once a year. There also are reclaimed water quality criteria for chlorine residual [2.0 mg/l]. The existing rules require monitoring for chlorine residual once a month.

Finally, the existing rules prescribe reclaimed water quality criteria for reclaimed water that is released to man-made wetlands marshes. There are criteria for fecal coliform [5-sample geometric mean of 1000 cfu/100 ml and a single sample maximum concentration of 4000 cfu/100 ml], pH [6.5 to 8.6 standard units], maximum daily pH change [0.5 standard units], dissolved oxygen [6.0 mg/l] and temperature ["no interference with aquatic life and wildlife"]. Reclaimed water that is released to a man-made wetlands marsh must meet surface water quality standards for trace substances to protect aquatic life and wildlife. Again, reuse permittees are not required to monitor routinely for trace substances.

4. Does ADEQ intend to revise the existing reuse criteria?

The numeric, criteria-based approach to reuse regulation has been criticized because its implementation relies upon extensive end-of-process compliance monitoring. Critics of this approach point out that not all parameters are capable of being adequately analyzed. It is argued that such monitoring involves complex, time-consuming, expensive and often insensitive analytical procedures and that few operators of wastewater treatment plants can employ the personnel and equipment necessary to perform the necessary analyses. Critics argue that better protection of the public health and the environment is provided by an approach which requires that wastewater undergo a prescribed treatment process which gives a reasonable assurance that the reclaimed water can be reused safely.

A suggested model for revision of Arizona's reuse rules is the California approach to wastewater reuse regulation. California has established statewide reclamation criteria based upon prescribed wastewater treatment processes. Descriptive terms for required treatment processes are used rather than numeric criteria for specific pollutants. For example, the California regulations require that wastewater be oxidized, clarified, coagulated, filtered and disinfected before it can be reused for open access landscape irrigation.

The California rules prescribe treatment processes that must be applied to wastewater that is reused for agricultural irrigation, turf irrigation, impoundments and ground water recharge. The California rules include definitions of adequate disinfection of wastewater. Disinfection requirements are expressed as maximum allowable total coliform concentrations. The California rules also

prescribe numeric criteria for turbidity and pH. To ensure that reclaimed water can be expected to be free of pollutants and pathogens, required treatment processes, monitoring requirements, operation and maintenance procedures and treatment reliability requirements are prescribed.

The California rules provide regulatory flexibility by recognizing that other methods of treatment besides the treatment trains that are prescribed in the rules may be used. The California rules state that other methods of treatment are acceptable if it can be demonstrated that an alternative method of treatment and its reliability features are equivalent to the treatment train prescribed in the rules.

ADEQ proposes to adopt the California approach and specify the treatment processes that must be applied to wastewater to provide reasonable assurance that the reclaimed water can be safely reused without adversely affecting public health and the environment. ADEQ also proposes to prescribe treatment reliability requirements for wastewater treatment plants that supply reclaimed water for reuse applications. The treatment reliability requirements are intended to ensure that treatment plants operate reliably and do not deliver indadequately treated wastewater to reuse sites. ADEQ will propose revisions to the BADCT guidance document for domestic and municipal wastewater treatment plants that address reclaimed water quality and treatment reliability.

ADEQ will propose that a limited number of numeric reclaimed water quality criteria be established and that wastewater treatment plants be required to monitor for these indicator parameters at the point where reclaimed water enters the distribution system. Monitoring requirements will provide information on whether required wastewater treatment processes are operating correctly. ADEQ will propose reclaimed water quality criteria and monitoring requirements for total coliform, pH and turbidity to ensure that reclaimed water that is supplied to a distribution system is adequately disinfected [See discussion in next section].

ADEQ may require additional monitoring [e.g. chlorine residual] by reclaimed water distribution system operators at the point of delivery to ensure that the microbiological quality of reclaimed water is not degraded in the distribution system.

It may be necessary to establish numeric reclaimed water quality criteria and monitoring requirements for total dissolved solids or total nitrogen for certain reuse applications. In addition, ADEQ is evaluating whether there is a need to prescribe reclaimed water quality criteria and monitoring requirements for toxic pollutants that may accumulate in soils or that may present a risk to human health through food consumption or partial body contact [See discussion on these topics in subsequent sections of this paper].

ADEQ Proposal: Adopt the California approach to reuse regulation and prescribe required treatment processes for various reuse applications in the BADCT guidance document for wastewater treatment plants. Limit end-of-process monitoring to traditional parameters such as total coliform, pH and turbidity. ADEQ invites public comment on the need to establish reclaimed water quality criteria and monitoring requirements for toxic pollutants, nutrients and total dissolved solids.

5. **What microbiological criteria will be established for reuse applications?**

The primary public health requirement for the reuse of reclaimed water is to assure an adequate level of microbiological water quality to prevent the transmission of waterborne diseases. A wide variety of pathogenic organisms may be found in wastewater. The bacteria, parasites and viruses in wastewater cause diseases such as hepatitis, gastroenteritis, diarrhea, giardiasis, dysentery, cholera, meningitis and respiratory illnesses.

The objective of prescribing reclaimed water quality criteria for microbiological pollutants is to reduce to acceptable levels the potential health hazards associated with human exposure to reclaimed water through various reuse applications. Advanced wastewater treatment systems are available that can remove virtually all of the pathogens in wastewater and reduce the risk of transmission of waterborne diseases to near zero. However, most wastewater treatment plants do not provide this level of treatment and achieving this amount of risk reduction may involve significant costs. Secondary treatment and disinfection can reduce significantly the number of pathogens in wastewater. However, secondary treatment alone does not assure the complete removal of disease-causing organisms. Consequently, there is a relatively greater risk associated with the reuse of reclaimed water that has received secondary treatment and disinfection as compared to reclaimed water that has undergone advanced treatment.

The amount of risk from the reuse of reclaimed water is difficult to assess. The amount of risk is dependent on the degree of human exposure to the reclaimed water, the reclaimed water quality and treatment reliability. The assessment of risk associated with the reuse of wastewater is complicated by many variables, including but not limited to factors related to: type and number of pathogens in the community, pathogen survival, infective doses of pathogens, persistence of pathogens in the environment and the susceptibility of individuals to disease [e.g., age, immune status, health]. Epidemiological evidence defining the health risks associated with wastewater reuse is limited.

The basic public policy issue in prescribing reclaimed water quality criteria is to determine what constitutes an acceptable level of risk from exposure to reclaimed water through various

reuse applications. The determination of acceptable risk is an uncertain enterprise given the limited amount of risk assessment information, the limited epidemiological data available and the lack of consensus by public health officials on the appropriate levels of treatment required for wastewater reuse.

Economic issues provide an important subtext to the risk assessment policy debate: Should owners of wastewater treatment plants be required to treat wastewater so that the risk to public health that is associated with the reuse of reclaimed water approaches zero? What are the treatment costs associated with such risk reduction? Are these treatment costs necessary or reasonable? Are there less expensive alternatives that will reduce risk to acceptable levels?

The public health can be protected in two basic ways:

(1) by limiting human exposure to reclaimed water, and
(2) by reducing the concentrations of pathogens in reclaimed water through treatment.

ADEQ proposes to utilize both approaches. ADEQ proposes to prescribe treatment requirements to reduce the concentrations of pathogens in reclaimed water. Where there is a high potential for human exposure to reclaimed water, the proposed treatment requirements are stringent. Where the potential for human exposure to reclaimed water is relatively small, treatment requirements are less stringent. ADEQ also will propose appropriate reuse site controls, worker protection provisions and distribution system requirements to further reduce the risk of human exposure to reclaimed water.

ADEQ is considering the establishment of three classes of reclaimed water [Classes A, B and C]. Class A reclaimed water is wastewater that has undergone advanced wastewater treatment and that is essentially pathogen-free. Class A reclaimed water is a wastewater that has undergone secondary treatment and which has been coagulated, flocculated, filtered and disinfected. ADEQ proposes to establish a maximum allowable total coliform concentration for Class A reclaimed water of 2.2 cfu/100 ml [5-sample geometric mean] and a single sample maximum concentration at 23 cfu/100 ml.

Class A reclaimed water may be used safely for all recognized reuse applications. ADEQ proposes to <u>require</u> Class A reclaimed water where there is the potential for ingestion of reclaimed water, food contamination, or where the potential for direct human contact with the reclaimed water is very high. ADEQ proposes to require Class A reclaimed water for surface or spray landscape irrigation where public access is unrestricted [e.g., schoolyards, playgrounds, parks]. Class A reclaimed water will be required for the surface or spray irrigation of food crops [including the spray irrigation of orchards and vineyards]. ADEQ proposes to require Class A

reclaimed water for use in recreational impoundments where full body contact recreation takes place.

Class B reclaimed water is a wastewater that has undergone secondary treatment, filtration and disinfection. ADEQ proposes to establish a maximum allowable total coliform concentration for Class B reclaimed water of 23 cfu/100 ml [5-sample geometric mean] and a single sample maximum concentration of 240 cfu/100 ml.

Class B reclaimed water may be used safely for landscape irrigation where public access is restricted. ADEQ proposes to require Class B reclaimed water in recreational impoundments where partial body contact recreation is permitted [e.g. boating] and in landscape impoundments. Finally, Class B reclaimed water may be used for toilet flushing.

Class C reclaimed water is a wastewater that has undergone secondary treatment and which has been disinfected. ADEQ proposes to establish a maximum allowable total coliform concentration for Class C reclaimed water [5-sample geometric mean] at 1000 cfu/100 ml and the single sample maximum concentration at 4000 cfu/100 ml. Class C reclaimed water may be used where there is a relatively small likelihood of human exposure to the reclaimed water. Class C reclaimed water may be used safely for the surface or spray irrigation of fiber, seed and forage crops; surface or spray irrigation of pastures; surface irrigation of orchards and vineyards, livestock watering and dust control. Finally, Class C reclaimed water may be used in constructed wetlands.

ADEQ invites comment on whether the proposed microbiological water quality criteria for Classes A, B and C and the application of these criteria to various reuse applications are appropriate.

ADEQ Proposal: Establish three classes of reclaimed water. Require advanced treatment of wastewater (coagulation, flocculation, filtration and disinfection) before it can be reused for the irrigation of food crops; open access landscape irrigation and recreational impoundments where full body contact takes place. Require secondary treatment, filtration and disinfection of reclaimed water for restricted access landscape irrigation, restricted recreational impoundments, landscape impoundments and toilet flushing. Require secondary treatment and disinfection for irrigation of fiber, seed and forage crops; pasture irrigation, livestock watering; dust control and constructed wetlands.

6. **What indicator of microbiological quality of reclaimed water should be used?**

ADEQ proposes to express disinfection requirements for reclaimed water in terms of maximum allowable total coliform concentrations. ADEQ proposes to use the total coliform bacteria group as an

indicator of the microbiological quality of reclaimed water because it is a standard indicator of disinfection effectiveness.

Total coliform organisms are good indicators of microbiological quality because: 1) total coliforms are present in reclaimed water in greater numbers than pathogens; 2) total coliforms generally are more resistant to disinfection than many (but not all) pathogens; 3) the analytical test for total coliforms is simple and inexpensive [a simple and inexpensive test will permit more frequent monitoring of the microbiological quality of reclaimed water]; and 4) it has been demonstrated in California that the prescribed treatment train for Class A reclaimed water in combination with compliance with the proposed total coliform disinfection criteria results in the production of an essentially virus-free reclaimed water.

The existing rules prescribe reclaimed water quality criteria for fecal coliform, viruses and parasites. ADEQ proposes to repeal the numeric criteria and monitoring requirements for enteric viruses, Giardia lamblia, Entamoeba histolytica, Ascaris lumbricoides and tapeworm and rely on total coliform as the single indicator of the microbiological quality of reclaimed water.

ADEQ proposes to eliminate the virus criteria for several reasons:

1. Virus criteria are unnecessary if the treatment process approach and total coliform disinfection criteria are adopted. The literature documents that the prescribed treatment train and compliance with the proposed disinfection criteria will result in effective removal of viruses from reclaimed water.
2. There is no consensus among public health official regarding the health significance of low levels of virus in reclaimed water.
3. Virus monitoring is expensive and complex, recovery rates are low and the laboratory procedures to determine the presence viruses and identify them can take up to a month.

There are alternative indicators of microbiological quality of reclaimed water that could be used in place of or in addition to total coliform. These include Enterococci, E. coli, fecal coliform, bacteriophages, human enteroviruses and parasites. ADEQ invites public comment on whether any of these is a more appropriate indicator of the microbiological quality of reclaimed water. ADEQ also is interested in obtaining public comments on whether the existing virus and parasite standards for reclaimed water should be retained or repealed.

ADEQ Proposal: Use total coliform concentrations a single indicator of the microbiological quality of reclaimed water. Eliminate existing reclaimed water quality criteria for viruses and parasites.

7. Turbidity

The need for standards for turbidity or total suspended solids is related to achieving compliance with prescribed microbiological water quality criteria. Turbidity or total suspended solids standards are necessary to assure that the disinfection system at the wastewater treatment plants is operating properly.

Many pathogenic organisms are associated with suspended solids. Suspended solids in reclaimed water can shield bacteria and viruses from the action of disinfectants. Also, the organic matter in reclaimed water consumes chlorine, making less chlorine available for disinfection. In order to assure adequate disinfection, suspended solids must be removed from wastewater prior to disinfection.

The existing rules prescribe a water quality criterion of 1 nephelometric turbidity unit (NTU) for reclaimed water that is used for the irrigation of food crops that are consumed raw and for impoundments where full body contact takes place [See Table I - "Allowable Permit Limits for Specific Reuses" in Appendix 1]. This 1 NTU standard is essentially a drinking water standard. A 5 NTU criterion is established for open access landscape irrigation and restricted recreational impoundments.

Arizona's 1 NTU criterion has been criticized on the ground that it is not technically feasible for a wastewater treatment plant to comply consistently. Consequently, the 1 NTU standard operates to prevent the reuse of reclaimed water for the irrigation of food crops and for recreational impoundments where full body contact is allowed. Currently, there are no reuse permits in Arizona for these reuse applications.

The California reclamation criteria require that reclaimed water meet a standard of 2 NTUs before it can be used for irrigation of food crops and for use in recreational impoundments where swimming is allowed. The California reclamation criterion states that turbidity may not "exceed an average operating turbidity of 2 turbidity units and does not exceed 5 turbidity units more than 5 percent of the time during any 24-hour period." This criterion is based on the professional judgment that compliance with a 2 NTU standard results in the production of an adequately clarified reclaimed water that is suitable for high level disinfection and that it is technically feasible to comply with a 2 NTU standard. Reclamation experience in California has shown that a 2 NTU turbidity level is achievable by well-operated wastewater treatment plants employing chemical coagulation and filtration treatment processes.

An alternative approach is to establish reclamation criteria for total suspended solids (TSS). The state of Florida has adopted this approach and established TSS criteria for irrigation with

reclaimed water. Florida requires a 24-hour composite TSS sample. No daily sample may exceed 5 mg/L TSS. The results of the analysis on a composite sample represent a daily average TSS value.

Florida apparently adopted a daily average TSS standard because of the ease of sample collection and analysis. However, it should be noted that, in practice, Florida has established an operating protocol for reclamation facilities under which turbidity is monitored continuously. A "set point" is established for turbidity in the range of 2.0 - 2.5 NTU. If turbidity exceeds this set point for a predetermined time, Florida requires that wastewater be routed to a holding facility or to alternative disposal until the treatment problem is fixed.

The Florida TSS standard is equivalent to the California average operating turbidity standard of 2 NTU because each NTU translates into approximately 2.3 - 2.4 mg/L of TSS. Thus, an "average operating turbidity" of 2 NTU is equivalent to a daily average of less than 5 mg/L of TSS.

ADEQ believes that a standard which requires continuous monitoring of turbidity is superior to TSS monitoring using 24-hour composite samples. A daily average TSS value does not provide the same level of reliability that the disinfection system at the source wastewater treatment plant is operating properly. ADEQ proposes to require continuous monitoring of turbidity to provide greater treatment reliability. ADEQ also proposes to revise the current turbidity standard from 1 NTU to 2 NTU.

ADEQ proposal: Adopt an average operating turbidity of 2 NTU, not to exceed 5 NTU more than 5 percent of the time during a 24-hour period for Class A reclaimed water. Adopt current 5 NTU standard for Class B reclaimed water. No turbidity requirements for Class C reclaimed water.

C. Agricultural Reuse

1. Current effluent usage

There are several irrigation districts in Arizona that currently use or are planning to use reclaimed water for agricultural irrigation. Some examples of agricultural reuse in Arizona include: 1) the Cortaro-Marana Irrigation District in Pima County which reused approximately 3,127 acre-feet of reclaimed water for irrigation of crops in 1988; and 2) the Ocotillo Water Reclamation Plant in Chandler which delivered about 2,700 acre-feet of reclaimed water to local farms for agricultural irrigation in 1988.

An example of reclaimed water reuse for agricultural irrigation on a large scale is the planned exchange between the City of Phoenix and the Roosevelt Irrigation District. The City of Phoenix is planning to enter into an exchange of reclaimed water for ground

water and surface water which will involve the delivery of approximately 30,000 acre-feet of reclaimed water to the Roosevelt Irrigation District for agricultural irrigation.

2. **Existing reclaimed water quality criteria**

The existing rules allow the reuse of reclaimed water for the irrigation of fiber, seed and forage crops; pastures and food crops. Separate reclaimed water quality criteria have been established for each of these agricultural reuse applications. The existing rules distinguish between food crops that are eaten raw and those that undergo additional processing to destroy pathogens [See Table I - "Allowable Permit Limits for Specific Reuses" in Appendix 1].

Under the existing rules, reclaimed water must meet a fecal coliform criterion of 1000 cfu/100 ml [5-sample geometric mean] and a single sample maximum criterion of 4000 cfu/100 ml for most agricultural irrigation. More stringent reclaimed water quality criteria apply to the irrigation of food crops that are consumed raw. For irrigation of food crops that are consumed raw, reclaimed water must meet a fecal coliform criterion of 2.2 cfu/100 ml [5-sample geometric mean] and a single sample maximum concentration of 25 cfu/100 ml. Reclaimed water that is used for irrigation of food crops that are consumed raw also must meet stringent virus and parasite standards [1 enteric virus unit/40 liters and no detectable Giardia lamblia cysts, Entamoeba histolytica or Ascaris lumbricoides].

3. **What are the proposed reclaimed water quality criteria for irrigation of food crops?**

ADEQ proposes to require Class A reclaimed water for the irrigation of food crops. This means that wastewater must receive secondary treatment + coagulation/flocculation + filtration + disinfection to 2.2 cfu/100 ml total coliform before it can be used to irrigate food crops. ADEQ proposes to eliminate the current distinction between food crops that are consumed raw and food crops that receive additional processing.

The proposed level of treatment is equivalent to the level of treatment that is required under the existing reuse rules for irrigation of food crops that are consumed raw. The existing rules prescribe a stringent enteric virus criterion for the irrigation of food crops that are consumed raw [1 enteric virus unit/40 liters]. This enteric virus criterion can be attained only by the application of wastewater treatment processes that include coagulation and filtration.

ADEQ proposes to repeal existing reclaimed water quality criteria for enteric virus and parasites in this rulemaking. However, compliance with the proposed technology-based requirements and

total coliform criteria will provide an equivalent level of human health protection and will assure that the reclaimed water that is used for irrigation of food crops is essentially virus-free. Virus studies have demonstrated that reclaimed water that has undergone the Class A treatment train and which meets a disinfection criterion of 2.2 cfu/100 ml total coliform is essentially free of bacteria, parasites and virus.

Stringent reclaimed water quality criteria are necessary for the spray irrigation of food crops because of the possibility of direct contact between reclaimed water and the edible portion of the food crop. A virtually pathogen-free irrigation water is required to eliminate the possibility of disease transmission through human consumption of contaminated food crops.

ADEQ proposes to require Class A reclaimed water for the surface irrigation of root crops [e.g., carrots, potatoes and onions]. Again, Class A reclaimed water is required because of the possibility of direct contact between the edible food crop and the reclaimed water.

ADEQ proposes to require Class A reclaimed water for the surface irrigation of food crops where there is usually a short distance between the irrigation water and the food crop [e.g., lettuce]. A high level of treatment is required because of the possibility of direct contact between the food crop and the irrigation water or contaminated soils. Pathogen contamination of food crops can occur because of splashing, transmission by vectors, windblown dust or flooding caused by overapplication of irrigation water.

ADEQ proposal: Class A reclaimed water will be required for the irrigation of food crops.

4. **What are the proposed reclaimed water quality criteria for irrigation of orchards and vineyards?**

ADEQ proposes to require Class A reclaimed water for the spray irrigation of orchards and vineyards because of the potential for direct contact between edible fruits and reclaimed water. However, a lower quality of reclaimed water may be used for the surface irrigation of orchards and vineyards because of the distance between the irrigation water and the edible portion of the food crop. Class C reclaimed water may be used safely for <u>surface</u> irrigation of orchards and vineyards. The current prohibition againsts the harvesting of fruit that has come into contact with the ground or irrigation water should be retained.

ADEQ proposal: ADEQ proposes to require Class C reclaimed water for the surface irrigation of orchards and vineyards. Class A reclaimed water will be required for spray irrigation of orchards and vineyards.

5. **What are the proposed criteria for irrigation of fiber, seed, forage crops?**

Primary effluent has been used in California for irrigation of fiber, seed and forage crops without adverse human health effects. ADEQ proposes to prohibit the reuse of primary effluent in Arizona. However, ADEQ believes that a lower quality of reclaimed water may be used safely for the irrigation of fiber, seed and forage crops because there is less human exposure and a lower potential for the transmission of waterborne diseases. With proper reuse site controls, adequate buffer zones and worker protection provisions, human exposure to reclaimed water that is used for irrigation of fiber, seed and forage crops can be minimized and the public health protected.

ADEQ proposal: ADEQ proposes to require Class C reclaimed water for irrigation of fiber, seed, forage crops.

6. **What are the proposed criteria for the irrigation of pastures?**

Arizona's current reuse regulations require that reclaimed water that is used for irrigation of pastures meet a fecal coliform criterion of 1000 cfu/100 ml [5-sample geometric mean] and be free of the common large tapeworm [i.e., "none detectable"]. The rationale for the parasite criterion for reclaimed water that is used for pasture irrigation is that reclaimed water may contain the eggs of the beef tapeworm, *Taenia saginata*. There is a possibility that cows that graze on pastures that are irrigated with reclaimed water may be infected with bovine cystercercosis [the larval stage of Taenia saginata]. Humans may then be infected by eating the undercooked meat of infected animals.

Arizona is the only state that has a parasite criterion for pasture irrigation. Other states rely on microbiological standards based on standard indicator organisms [e.g., fecal or total coliform criteria]. Most other states permit the use of reclaimed water that has received secondary treatment and disinfection for the irrigation of pastures [e.g., California, Florida, Oregon, Washington].

However, there is some question as to whether secondary treatment and disinfection alone are adequate to eliminate parasites, particularly helminth eggs, from reclaimed water. The World Health Organization [WHO] has recommended microbiological quality guidelines for wastewater use in agriculture. The WHO guidelines include design goals for the number of helminth eggs in wastewater that is used for the irrigation of pasture. WHO recommends that 99.9% of all helminth eggs be removed from wastewater <u>in areas where helminthic diseases are endemic and where such diseases present actual health risks</u> [emphasis added]. WHO recommends that intestinal nematodes be used as indicator organisms for helminth removal [i.e., Ascaris and Trichuris species and hookworms] and

are effective indicators of disinfection effectiveness. Also, total coliform analysis is widely used, simple and inexpensive.

4. The adoption of less stringent microbiological criteria might be justifiable if reuse site controls and worker protection provisions are fully implemented. However, such precautions are not always fully implemented by operators of reuse sites. The adoption of stringent total coliform criteria for reclaimed water will provide a margin of safety.
5. Research on pathogen survival indicates that a small percentage of pathogens found in reclaimed water may persist in the environment for extended periods of time. The presence of pathogens on food crops presents a risk of disease transmission to an exposed human population. Current research indicates that while pathogens on food crops are destroyed by exposure to sunlight, starvation, predation by other organisms or by chemical agents, there is no assurance of complete pathogen destruction by these mechanisms. For this reason, a virtually pathogen-free effluent should be required for the irrigation of food crops.

ADEQ proposes to eliminate the distinction that exists in the current rules for food crops that are eaten raw and food crops that are processed. Under the existing rules, a lower quality of reclaimed water may be used to irrigate food crops that receive subsequent processing to destroy pathogens. ADEQ has no ability to monitor whether food crops that are irrigated with reclaimed water receive additional processing to destroy pathogens or not.

7. **Should ADEQ adopt salinity criteria for reclaimed water that is used for agricultural irrigation?**

Salinity is described as the single most important parameter for determining the suitability of water for agricultural irrigation. Salinity is generally understood as the measure of dissolved salts in water. It is usually determined by measuring the electrical conductivity of water. Salinity is often referred to as the concentration of total dissolved solids [TDS] in water.

All irrigation water contains dissolved salts. When irrigation water is taken up by plants or evaporates from the soil, the salts are left behind. The rate of accumulation of salt in soils depends on the salinity of the irrigation water and the rate at which salt is removed from the soil profile through leaching.

Crop plant damage and adverse soil impacts are closely tied to excessive soil salinity. In general, high concentrations of TDS in reclaimed water can have three adverse effects: 1) stunted plant growth; 2) specific ion toxicity; and 3) reduced soil permeability.

High TDS concentrations in irrigation water may stunt plant growth by altering the salt balance between the soil and the crop plants. As crop plants make adjustments to maintain the proper salt balance between plant tissues and the soil to obtain water, plant growth is impeded. The accumulation of salts in the soil also reduces the amount of water that is available to crops. As soil salinity increases, more frequent irrigations are required. Excess irrigation water must be applied to leach accumulated salts beyond the root zone to maintain favorable growing conditions for crops.

Some crops are sensitive to particular salts. Phytotoxicity occurs when a specific ion accumulates in a plant in an amount that damages the plant or reduces yields. Some crops exhibit specific ion toxicity to boron, chloride and sodium. High concentrations of these ions can cause subnormal growth rates, wilting and leaf burn.

The most prevalent phytotoxicity problem from the use of reclaimed water for agricultural irrigation is from boron. Reclaimed water may have high concentrations of boron because boron is a common ingredient in household detergents. Although small concentrations of boron are essential to plant growth, boron is toxic to plants in concentrations that are only slightly greater than the concentrations required for good plant growth. Plants grown on soils whose water-extractable boron is less than 0.4 mg/L may exhibit boron deficiencies. However, concentrations of boron in excess of 1.0 mg/L are toxic to boron-sensitive crops such as citrus and fruit crops. Excessive boron concentrations may cause leaf tip and marginal burn, leaf cupping, chlorosis, leaf drop, branch dieback and reduced growth in plants.

Chlorides also are phytotoxic. Foliar absorption of chlorides may cause plant damage to woody plant species at fairly low concentrations. Foliar absorption of chlorides is especially problematic when crops are irrigated with overhead sprinklers during periods of high temperature and low humidity. Excessive concentrations of chlorides in reclaimed water can cause leaf burn, chlorosis and twig dieback, especially in citrus crops.

Reclaimed water may be high in sodium, particularly in communities where there is extensive use of water softeners. High sodium concentrations in reclaimed water may adversely affect soil conditions. High sodium concentrations in irrigation water may decrease soil permeability and reduce soil aeration (depending on the sodium absorption ratio of the soil). Decreases in soil permeability reduce infiltration rates and may make it difficult to supply crops with enough water. Secondary problems such as crusting, excessive weed growth and oxygen deficiencies result from poor soil structure and surface waterlogging. High sodium concentrations also can have direct adverse effects on sensitive crops (nutritional imbalances, leaf burn, chlorosis and twig dieback).

The adverse effects associated with high TDS concentrations in irrigation water raise several regulatory questions. First, should ADEQ prescribe numeric TDS criteria for reclaimed water that is used for agricultural irrigation? Second, should ADEQ prescribe reclaimed water quality criteria to prevent specific ion toxicity? Should sodium concentrations be regulated in some way to prevent adverse soil impacts? If so, what should the reclaimed water quality criteria be?

There are general guidelines available that correlate salinity and restrictions on the use of reclaimed water for agricultural irrigation. For example, there is a salinity guideline table in Irrigation With Reclaimed Municipal Wastewater-A Guidance Manual by G. Stuart Pettygrove and Takashi Asano [Lewis Publishers, Inc., 121 South Main Street, Chelsea, Michigan (1985)(p. 3-11)]. The table indicates that there are no restrictions on the use of reclaimed water for agricultural irrigation in California if the TDS concentration of irrigation water is less than 450 mg/L. There is a slight to moderate restriction on agricultural use if the TDS concentration of irrigation water is between 450 and 2000 mg/l. There is a severe restriction on agricultural use if the TDS concentration of the irrigation water exceeds 2000 mg/L. Similar guidelines for total dissolved solids in irrigation water are recommended by EPA [See Appendix 4].

ADEQ could prescribe reclaimed water quality criteria for TDS based upon these or similar general guidelines. For example, ADEQ could prohibit the reuse of reclaimed water for agricultural irrigation if the TDS concentration in irrigation water exceeds 2000 mg/L or require the implemen-tation of best management practices for salinity control if the TDS concentration of the reclaimed water is between 450 and 2000 mg/L.

A problem with the promulgation of general TDS criteria is that there are many site-specific variables that affect the maximum allowable TDS concentration in irrigation water. Maximum allowable TDS concentrations will vary depending on the type of crops that are irrigated, local climate, the type of soil, drainage conditions, the method of irrigation that is used and the amount of irrigation water applied. These site-specific variables may render a general TDS criterion inapplicable.

Also, the regulation of TDS in reclaimed water is probably not cost-effective. Total dissolved solids in wastewater are not removed through conventional secondary treatment or even by many advanced wastewater treatment technologies. The removal of dissolved solids from wastewater usually requires treatment of wastewater by membrane filtration techniques [e.g., reverse osmosis or nanofiltration] or by distillation. These wastewater treatment technologies are very expensive and they present significant brine disposal problems in large scale applications. The cost of using reverse osmosis or nanofiltration to produce reclaimed water for

agricultural irrigation is probably prohibitive. Because of the high cost of TDS removal, it is cheaper to use ground water or surface water for irrigation. A rule which requires TDS removal wouuld effectively prevent the reuse of reclaimed water for agricultural irrigation.

A more practical approach to salinity control may be to promulgate rules that regulate the amount of reclaimed water that can be applied for agricultural irrigation. An irrigation water management approach to salinity control would be based on the general principle of salt leaching. Leaching is the deliberate over-application of irrigation water in excess of crop needs to establish a downward movement of salts in the soil profile. If more reclaimed water is applied than the crop uses, the excess reclaimed water will leach salts below the root zone. The application of reclaimed water in the proper amounts can stabilize soil salinity at a fairly constant value. The soil salinity value is dependent on the leaching fraction (i.e., the fraction of irrigation water that passes through the root zone, removes salts and is then discharged as drainage water).

ADEQ could require the development of water balances for reuse sites which incorporate a leaching fraction to provide salinity control. The inclusion of a leaching fraction in a reuse site water balance also could be used to prevent ground water contamination and waste due to the over-application of irrigation water.

There are significant regulatory problems associated with an irrigation water management approach to salinity control. First, it probably is not feasible to implement this approach in the absence of an individual permit for the application of irrigation water. This presents a legal problem. An individual APP for the application of irrigation water is legally precluded by A.R.S. §49-250.B.15. This statute exempts the application of water for agricultural or landscape irrigation from any source, including wastewater, from individual APP requirements.

Second, it probably is not feasible for ADEQ to prescribe water balances for reuse sites in a general permit. Many site-specific factors will affect the consumptive use of water at individual reuse sites. Important natural factors that affect consumptive use include local climate, soils and topography. Temperature, precipitation, humidity and wind movement will affect consumptive use of irrigation water at an individual reuse site. Management factors that affect consumptive use include the planting date of crops, crop variety, fertility, plant spacing, irrigation scheduling, irrigation efficiency, cultivation and chemical spraying. Other miscellaneous water requirements which affect total irrigation water demand include the use of water for leaching, frost protection, crop cooling and pest control. All of these factors influence the amount of water that is used at an

individual reuse site. Consumptive use requirements will vary from farm to farm, season to season and day to day. These site-specific and temporal variations are very difficult to address through a general permit.

Any water balance will require frequent modification as irrigation water demands change over time. It is highly unlikely that ADEQ can update water balances in a timely manner given current agency resource constraints. Finally, even if a general APP could be issued with a water balance requirement, ADEQ does not have the staff resources to monitor whether growers apply reclaimed water in compliance with water balance requirements.

The third alternative is simply not to regulate TDS concentrations in reclaimed water and to leave irrigation water management decisions to the users of reclaimed water. Arguably, government regulation is unnecessary because it is in the grower's self-interest to provide effective salinity control for sustainable agriculture.

Also, the regulation of salinity in reclaimed water may be unnecessary, especially when the average TDS concentration of reclaimed water from a wastewater treatment plant is relatively low in comparison to water from other sources. For example, the monthly average TDS concentration in the effluent from the Roger Road WWTP for the period October, 1981 through September, 1982 was 535 mg/l. The monthly average TDS concentration of the effluent from the Ina Road WWTP for the same time period was 471 mg/l [Source: Tucson Metropolitan Wastewater Reuse Assessment (hereafter Tucson Reuse Assessment, CH2M Hill/Ruber & Hager Joint Venture, Table 2-1 on p. 2-5].

The effluent from the City of Phoenix wastewater treatment plants have TDS concentrations that are slightly higher than that reported for the Pima County wastewater treatment plants. In 1987, the average TDS concentration of the effluent from the 91st Avenue wastewater treatment plant in Phoenix was 758 mg/l. The average TDS concentration of the effluent from the 23rd Avenue wastewater treatment plant was 703 mg/l [Source: City of Phoenix Potable Reuse Feasibility Study, Final Report, November, 1988, Table 1-5].

These monthly averages are close to the "no restrictions" end of the general salinity guidelines for agricultural use described earlier. Also, these average TDS concentrations compare favorably to TDS concentrations in surface water and ground water. For example, surface water in the Central Arizona Project canal is expected to range between 537-730 mg/L TDS. The salinity of the lower Colorado River typically ranges between 600-800 mg/L depending upon flow and the point of diversion. The salinity of the Salt River ranges between 500-700 mg/L.

Currently, there are no water quality standards for TDS for

aquifers or for navigable waters in Arizona [except for the Colorado River]. Arguably, TDS standards for reclaimed water are inappropriate when there are no TDS standards for surface water or ground water. Any regulation of salinity should take salt inputs from other water sources into consideration. Salinity control regulations for reclaimed water should not be developed in isolation.

The long-term build up of salt in soils and the possibility of ground water salinization are matters of environmental concern. However, ADEQ believes that reclaimed water quality criteria for salinity are unnecessary at this time. ADEQ favors an approach that leaves irrigation water management and salinity control decisions at the user level. Growers are in the best position to adjust irrigation water management practices on a site-specific basis to account for the salinity of reclaimed water that is used for agricultural irrigation. If salinity control rules are to be developed, they should be developed in conjunction with salinity control rules for surface water and ground water.

ADEQ Proposal: Do not regulate salinity in reclaimed water at this time.

8. **Should ADEQ regulate nitrogen concentrations in reclaimed water?**

Nitrogen is an essential plant nutrient that is necessary for the production of food, fiber, seed and forage crops. Nitrogen and other nutrients are present in reclaimed water and provide important fertilizer benefits. However, in some cases, total nitrogen concentrations in reclaimed water may be in excess of crop plant needs. Excessively high total nitrogen concentrations can cause excessive vegetative growth at the expense of fruit production, delay crop maturity or reduce crop quality (e.g., reduced sugar or starch content, poor flavor and texture). Also, excessively high total nitrogen concentrations in reclaimed water may cause pollution of navigable waters or nitrate contamination of ground water.

The fate and transport of nitrogen in the soil is extremely complex. There are a number of chemical, physical and biological processes that affect the fate of nitrogen in the soil after the application of reclaimed wastewater for irrigation. These processes include nitrogen fixing, NH^{+4} adsorption and retention, nitrogen transformations in the soil (e.g., mineralization, nitrification and denitrification), volatilization of ammonia and plant uptake.

Total nitrogen that is not removed by these processes may be transported to navigable waters through agricultural return flows or it may move through the soil profile to ground water as nitrate. The amount of nitrate that is leached to ground water depends upon

the processes described above, the quantity of reclaimed water that is applied, evapotranspiration rates, nitrogen utilization, fertilizer applications and soil profile characteristics.

The nitrate contamination of ground water is a public health concern. The primary public health concern arising from nitrate contamination of drinking water is the risk of methomoglobinemia, or "blue baby disease." High concentrations of nitrate in drinking water may interfere with the oxygen-carrying capacity of the blood of infants. EPA has established a National Primary Drinking Water Maximum Contaminant Level (MCL) for nitrate of 10 mg/l to protect infants from this disease. This MCL has been adopted as an aquifer water quality standard in Arizona. It also has been adopted as a water quality standard to protect navigable waters with the domestic water source designated use. Obviously, total nitrogen concentrations of reclaimed water that is used for agricultural irrigation may not cause violations of these applicable water quality standards.

There are several ways that total nitrogen concentrations in reclaimed water may be regulated to prevent nitrate contamination of ground water or violations of water quality standards for total nitrogen that are established for navigable waters:

1. Require a nitrogen budget for reuse sites. Manage total nitrogen loading through irrigation water management. Calculate the allowable annual hydraulic loading rate that will result in compliance with a nitrate limit of 10 mg/l [See G. Pettygrove and T. Asano, Irrigation with Reclaimed Municipal Wastewater, A Guidance Manual, Chapter 8, Irrigation System Design, p. 8-1].
2. Require nitrogen removal at the source wastewater treatment plant to reduce total nitrogen concentrations in the reclaimed water. Require wastewater treatment plants to meet a 10 mg/l total nitrogen (as N) standard unless it can be demonstrated that reuse site characteristics permit the release of reclaimed water with higher total nitrogen concentrations.
3. Rely on best management practices required under the general APP for application of nitrogen fertilizers. Do not regulate the concentration of total nitrogen in reclaimed water.

ADEQ does not believe that total nitrogen concentrations in reclaimed water should be regulated through the development of nitrogen budgets. ADEQ believes that nitrogen budgeting is unrealistic for many of the same reasons that argue against regulation of salinity.

First, nitrogen budgets cannot be prescribed except through an individual permit. ADEQ is legally precluded from issuing individual APPs for the application of irrigation water at reuse sites. Second, it is unlikely that nitrogen budgets can be administered through a general permit. Third, ADEQ resource

constraints effectively preclude the development of nitrogen budgets for individual reuse sites. Even if ADEQ required the development of a nitrogen budget for a reuse site in a general APP, ADEQ does not have the staff resources to monitor compliance with nitrogen loading requirements. Fourth, individual nitrogen budgets are impractical. Total nitrogen requirements will vary over time and from reuse site to reuse site. Source wastewater treatment plants cannot tailor the nitrogen concentration in the supply of reclaimed water to meet needs at individual reuse sites.

ADEQ proposes to rely on BADCT requirements to regulate the discharge of total nitrogen from wastewater treatment plants. The BADCT guidance document for domestic and municipal wastewater treatment plants defines the optimum reduction of nitrogen through the application of best control technology as less than 10.0 mg/L as N. Attainment of this treatment level requires the application of nitrogen removal technology at the wastewater treatment plant. The BADCT guidance document states:

> Denitrification technology is well developed at full-scale. Wastewater treatment plants with a sufficient economic base, skilled operators and reliably controlled pH, temperature, loading and chemical feed can achieve nitrogen effluent concentrations as low as 1 mg/L total nitrogen. Small package treatment plants can readily achieve treatment levels between 5 and 10 mg/L total nitrogen.

The BADCT guidance document recognizes that site characteristics may be available to meet nitrogen removal requirements [See Draft <u>BADCT Guidance Document for Domestic and Municipal Wastewater Treatment Plants</u>, pp. 32-36]. The operator of a wastewater treatment plant may be able to demonstrate that reuse site characteristics can be used to attain optimum reductions of total nitrogen as an alternative to nitrogen removal technologies at the source wastewater treatment plant.

ADEQ proposes to require nitrogen removal at the source wastewater treatment plant to less than 10 mg/L unless it can be demonstrated that reuse site characteristics permit the delivery of reclaimed water with higher concentrations of total nitrogen. Nitrogen removal at source wastewater treatment plants should be required unless it can be demonstrated that reuse site characteristics are available to control the discharge of nitrates to ground water.

Also, it should be noted that total nitrogen inputs are regulated under the agricultural general permit for the application of nitrogen fertilizers issued pursuant to A.R.S. §49-247. All persons who are engaged in the application of nitrogen fertilizers are required to limit fertilizer applications to the amount necessary to meet projected crop plant needs. The application of irrigation water must be managed and timed to minimize nitrogen

losses through leaching and runoff. In considering the use of reclaimed water for agricultural irrigation, the input of total nitrogen from reclaimed water should be factored into the determination of appropriate fertilizer application rates. Growers who use reclaimed water for irrigation should adjust fertilizer applications to account for the total nitrogen inputs from the irrigation water.

ADEQ Proposal: Rely on BADCT requirements for wastewater treatment plants and agricultural general permits for the application of nitrogen fertilizers to regulate total nitrogen concentrations in reclaimed water. Require nitrogen removal at source wastewater treatment plants to less than 10 mg/L, unless it can be demonstrated that a higher concentration of total nitrogen can be discharged by the source wastewater treatment plant and the nitrogen will be utilized by plants at reuse sites.

9. **Toxic pollutants**

Toxic pollutants may be present in reclaimed water in low concentrations, especially if a source wastewater treatment plant receives discharges from industrial users of the community sewer system. As a general rule, the concentrations of toxic pollutants in reclaimed wastewater are not high enough to cause short-term harmful effects when the water is used for agricultural irrigation. However, some toxic pollutants accumulate in soils and may have long-term harmful effects.

The uncontrolled discharge of toxic pollutants to soils is undesirable because once toxic pollutants accumulate in soils, they are difficult to remove. Soil contamination may result in: 1) toxicity to plants grown on affected soils, 2) absorption of toxic pollutants by crops resulting in contamination that is harmful to animal or human consumers of the crops, and 3) transport of toxic pollutants from soils to ground water or to navigable waters.

ADEQ could prescribe numeric criteria for toxic pollutants for reclaimed water that is used for agricultural irrigation. Reclaimed water quality criteria could be based on EPA guidelines which recommend maximum concentrations for pollutants in irrigation waters [See Appendix 4]. These EPA-recommended limits prescribe the maximum concentrations of pollutants for both long-term continuous use and short-term use of reclaimed water for irrigation.

A numeric, criteria-based approach would be similar to the approach that is used in the existing reuse rules. The existing rule, A.A.C. R18-9-703.A, states that concentrations of trace substances, organic chemicals, toxic substances and radiochemicals in waters used for agricultural irrigation must meet allowable limits prescribed in state-adopted water quality standards.

a. **Trace elements**

Small amounts of trace elements [e.g., boron, cadmium, chromium, copper, lead, molybdenum, nickel and zinc] are found in reclaimed water. Trace elements may be present because they are naturally occurring or because of discharges from industrial users of the community sewer system. Some trace elements are present because of the deterioration of public water supply system pipelines and household plumbing fixtures [e.g., lead and copper].

Some trace elements, particularly heavy metals, are of environmental concern because they can accumulate in soils and become toxic to crop plants or to their animal or human consumers. The metals of greatest concern are cadmium, copper, molybdenum, nickel and zinc.

Cadmium is phytotoxic to beans, beets and turnips at concentrations as low as 0.1 mg/L and is a concern because of the possibility of its entry into the human food chain. Copper is phytotoxic to a number of plants at 0.1 to 1.0 mg/L. Molybdenum is readily absorbed by crops. It is nontoxic to crop plants at the concentrations usually found in wastewater. However, molybdenum concentrations in livestock feed as low as 5 mg/kg may be toxic to livestock animals. Zinc is toxic to many plants at varying concentrations.

Conventional wastewater treatment plants are not specifically designed to remove metals. However, secondary wastewater treatment systems remove metals from wastewater because the metals are typically adsorbed on or precipitated by suspended solids. Metals are effectively removed from wastewater with the removal of the suspended solids. In general, metals concentrations in wastewater are reduced 70 to 90 percent by secondary treatment.

Typical concentrations of selected trace elements in secondary effluents and the EPA water quality criteria for long-term irrigation for those trace elements are summarized in the following table:

Element	Median concentration in secondary effluent [in mg/L]	Water quality criteria for irrigation [long-term] [in mg/L]
Arsenic	<0.005	0.10
Boron	0.7	0.75
Cadmium	<0.005	0.01
Chromium	0.02	0.10
Copper	0.04	0.20
Lead	0.008	5.00
Molybdenum	0.007	0.01
Nickel	0.004	0.20
Selenium	0.005	0.02
Zinc	0.04	2.00

[Source: G. Stuart Pettygrove and Takashi Asano, Irrigation With Reclaimed Water-A Guidance Manual, Lewis Publishers, Inc., 121 S. Main Street, P.O. Drawer 519, Chelsea, MI, p. 13-3].

A comparison of the median concentrations of trace elements in typical secondary effluent with the EPA water quality criteria for long-term irrigation shows that the EPA criteria for long-term irrigation are met through secondary treatment alone [with the possible exception of boron]. ADEQ believes that secondary treatment, in combination with implementation of an effective local pretreatment program to regulate industrial users that discharge to the community sewer system, should produce a reclaimed water that meets the EPA-recommended limits for agricultural irrigation.

The application of secondary treatment + coagulation/flocculation + filtration technologies to produce Class A reclaimed water or secondary treatment and filtration to produce Class B reclaimed water will result in even greater removals of suspended solids. Consequently, the treatment trains to produce Class A and Class B reclaimed water should result in compliance with all of the EPA-recommended limits for long-term use of reclaimed water for agricultural irrigation.

b. Priority pollutants

There are thousands of synthetic organic chemicals in the environment. Of these, the Clean Water Act requires that 65 compounds and families of compounds be regulated as toxic pollutants [See §307(a) of the Clean Water Act]. The Environmental Protection Agency has further identified 126 chemicals of concern under §307(a). These 126 pollutants are known as the priority pollutants.

The presence of priority pollutants in reclaimed water raises concerns about the potential adverse human health effects and the environmental risks associated with the reuse of reclaimed water for agricultural irrigation.

The toxicological research that has been done to date on the priority pollutants has focused primarily on human health effects related to exposure to priority pollutants through direct ingestion of water or fish and the acutely and chronically toxic effects of priority pollutants on aquatic life. Very little toxicological data or risk assessment information is available pertaining to human health exposure to priority pollutants thorugh food crops that have been irrigated with reclaimed water.

Some generalizations can be made. The route of human exposure to priority pollutants through the use of reclaimed water for agricultural irrigation is not direct ingestion of water. Instead, any priority pollutants that may be present in reclaimed water are deposited on soil, subjected to attenuation by physical, chemical

and biological means in the field and then translocated into plant tissue before they may enter the human food chain. The other possible route of human exposure to priority pollutants in reclaimed water is if the reclaimed water leaches to ground water after irrigation.

There are few data available to describe the environmental fate of priority pollutants in soils when reclaimed water is used for agricultural irrigation. However, some general conclusions can be made by comparing the soil adsorption coefficients, water-air partition coefficients and octanol-water partition coefficients of organic priority pollutants with those of pesticides whose environmental fate and transport in soils are better understood.

In general, it appears that organic priority pollutants are attenuated in the soil in a manner similar to the attenuation of pesticide residues [See G. Stuart Pettygrove and Takashi Asano, Irrigation With Reclaimed Municipal Wastewater-A Guidance Manual, Lewis Publishers Inc., 121 S. Main Street, P.O. Box Drawer 519, Chelsea, MI (1985), p. 15-16]. The authors conclude that because the concentrations of organic priority pollutants are usually much smaller than the concentration of pesticide residues, the environmental risk associated with their presence in reclaimed water is not significant.

This conclusion is supported by research on the fate of priority pollutants in publicly-owned wastewater treatment plants [See Fate of Priority Pollutants in Publicly Owned Treatment Works, Final Report, Volume 1, EPA 440/1-82/303, United States Environmental Protection Agency, Effluent Guidelines Division, Washington, D.C. (Sept. 1982]. EPA studied 50 publicly-owned treatment works and found that a total of 90 out of the 126 priority pollutants were detected at least once in POTW effluents. However, the priority pollutant occurrence data showed that only 30 priority pollutants were detected in 10 percent or more of the effluent samples and only 12 priority pollutants were measured in 50 percent or more of the samples. Of these, the most commonly found priority pollutants were metals [5 of 12], not organic priority pollutants.

These conclusions are consistent with effluent quality data from wastewater treatment plants in Arizona. For example, the 1989-1990 annual pretreatment reports for the regional wastewater treatment plants in Tucson and Phoenix indicate that relatively few priority pollutants [27] are detected in effluents. Of the 27 priority pollutants detected, 14 are metals. The available effluent quality data indicates that the 13 organic priority pollutants that were detected in effluents were present in extremely low concentrations which did not violate applicable water quality standards.

ADEQ believes that the organic priority pollutants in reclaimed water do not present a significant environmental risk given their low frequency of detection in effluent, their extremely low

concentrations in reclaimed water and their attenuation in the field through adsorption, volatilization and biodegradation.

ADEQ Proposal: Do not adopt numeric reclaimed water quality criteria for toxic pollutants. Rely on the proposed treatment train requirements and local pretreatment programs to provide effective control over the discharge of toxic pollutants in reclaimed water used for agricultural irrigation.

10. **Chlorine residual**

Free chlorine residuals at concentrations less than 1 mg/L usually pose no problem to crop plants. However, some woody crops are sensitive to chlorine. Excessive chlorine in reclaimed water may cause leaf burn when sprayed directly on foliage. Chlorine residuals at concentrations greater than 5 mg/L cause severe damage to most plants.

ADEQ proposes to require a chlorine residual of 2 mg/L for agricultural irrigation to protect public health. Source wastewater treatment plants and reclaimed water distribution systems will be required to maintain a chlorine residual of 2 mg/L to mitigate regrowth of bacteria.

ADEQ Proposal: Require a 2 mg/L chlorine residual for agricultural irrigation.

11. **Buffer zones**

Many states require buffer zones around agricultural areas that are irrigated with reclaimed water. The size of the buffer zone depends on the level of treatment the reclaimed water has received and the means of application.

Buffer zones are established primarily to mitigate the risk of disease transmission by human exposure to reclaimed water aerosols associated with spray irrigation. Viruses and bacteria in reclaimed water aerosols are in the respirable size range. The inhalation of reclaimed water aerosols is therefore a direct means of disease transmission.

Studies have shown that the bacteria and viruses in reclaimed water aerosols can travel considerable distances. The distance traveled by reclaimed water aerosols depends upon a number of factors, including the initial concentration of bacteria and viruses in the reclaimed water, the size of droplets, the amount of reclaimed water that is aerosolized, wind velocity, relative humidity, temperature and the time of irrigation. For example, one study found that coliform bacteria were carried up to 426 feet with a wind velocity of only 3.4 miles per hour. Another study found that the mean net bacterial aerosol levels [i.e. the observed bacterial aerosol level minus the mean upwind bacterial level] was 485 colony

forming units per cubic meter at a distance of 98 feet from the sprinkler heads.

Because of the lack of data regarding the incidence of human disease associated with exposure to wastewater aerosols, it is difficult to assess the health risk associated with spray irrigation with reclaimed water. However, most of the epidemiological studies have not detected a correlation between exposure to reclaimed water aerosols and illness. The research conducted to date seems to indicate that the health risk associated with reclaimed water aerosols for spray irrigation sites is low, especially when reclaimed water is disinfected. However, until more definitive studies are conducted to evaluate the ability of pathogens contained in reclaimed water aerosols to cause disease, ADEQ believes that it is prudent to limit human exposure to Class C reclaimed water by requiring a buffer zone around spray irrigated areas.

As noted above, many states have established such safeguards. For example, Illinois requires a 150-foot setback from a spray-irrigated reuse site to any residential lot. Florida requires a 500-foot setback to potable water supply wells and a 100-foot setback to property lines for sites where reclaimed water is used for agricultural irrigation of non-food crops. Colorado recommends a 500-foot setback from reuse sites to domestic water supply wells and 100-foot setback distance to any irrigation well.

In recent proposed revisions to California's reclamation criteria, California proposed the establishment of a 500-foot buffer zone for reuse sites that are spray irrigated with certain classes of reclaimed water. No buffer zones are required for reuse sites that are irrigated with highly treated reclaimed water [i.e, Class A and Class B reclaimed water]. This is similar to buffer zone requirements in Oregon and Nevada. These states do not require buffer zones when reclaimed water is used for unrestricted landscape irrigation or irrigation of food crops because of the high degree of treatment of the reclaimed water. However, buffer zones are required for the irrigation of non-food crops and restricted urban reuse because the reclaimed water that is used for such purposes does not receive a high level of treatment.

ADEQ proposes the following buffer zone requirements:

1. No buffer zone will be required for reuse sites irrigated with Class A or Class B reclaimed water because of the high quality of the reclaimed water.
2. ADEQ proposes a 500-foot setback requirement from the perimeter of the irrigated area to adjacent property lines for reuse sites that are spray irrigated with Class C reclaimed water.

12. Stormwater runoff controls

The existing reuse rule require that reuse sites be designed to contain the runoff from a 10-year, 24-hour precipitation event. This stormwater runoff control requirement does not apply if the reclaimed water meets the standards and conditions of a valid NPDES permit for a discharge to the waters of the United States. The current stormwater runoff provision does not apply to agricultural return flows. Finally, it does not apply to runoff from highway medians and golf courses if ADEQ determines that the runoff does not present a danger to the public [See A.A.C. R18-9-702.F in Appendix 1].

ADEQ proposes to repeal stormwater runoff requirements because of the high level of treatment for reclaimed water that are being proposed. In general, both Class A and Class B reclaimed water are of higher microbiological quality than typical stormwater runoff. The total coliform concentrations in stormwater runoff normally far exceed the allowable total coliform concentrations that are proposed for Classes A and B reclaimed water. Therefore, ADEQ sees no need to impose stormwater runoff controls for reuse sites.

The reuse of effluent from small, package wastewater treatment plants may present special problems. The quality of effluent from package plants can be highly variable and there is a greater risk of disinfection failure. Runoff containment of effluent from package treatment plants is one of the better tools available to protect public health. ADEQ probably will retain the stormwater runoff requirement for on-site wastewater treatment plants when it promulgates rules for such systems.

ADEQ Proposal: Repeal stormwater runoff control requirements.

URBAN REUSE

Reclamation systems may provide reclaimed water for a variety of purposes in urban environments, including:

1. Landscape irrigation [e.g. irrigation of golf courses, parks, school yards, cemeteries, commercial and residential areas and highway medians and shoulders];
2. Recreational and landscape impoundments;
3. Toilet flushing; and
4. Street washing.

A. Landscape irrigation

Water that is used for landscape irrigation is a significant percentage of the average total water usage in a potable water supply system. The average total water usage in a potable water system nationally is estimated to be 180 gallons per capita per day [GPCD]. Of this total, it is estimated that approximately 50% is used for outdoor purposes, principally for landscape irrigation.

For an Arizona example, the water use data from the Second Tucson Active Management Plan is instructive. Total GPCD among large water providers in the Tucson Active Management Area in 1985 was 170 GPCD. Of this total, it is estimated that the average residential water use rate was 108 GPCD. In general, residential water use in the Tucson AMA in 1985 was conservative with an estimated average interior water use rate of 74 GPCD and an estimated exterior water use rate of 34 GPCD. The exterior water use rate includes the use of water for landscape irrigation, pools, evaporative coolers and other incidental uses. The 1985 non-residential water use rate in the Tucson AMA was 42 GPCD. Major nonresidential uses include the use of water for irrigation of golf courses and parks. It can be safely assumed that a significant percentage of the exterior water use rate and the nonresidential water use rate in Tucson is for landscape irrigation. Thus, of the total water use rate of 170 GPCD, between 34 and 76 GPCD was used for landscape irrigation. This means that 20% to 50% of all of the potable water used in the Tucson AMA in 1985 was for landscape irrigation. Obviously, the substitution of reclaimed water for the potable water used for landscape irrigation in Tucson can significantly augment the potable water supply.

1. Current reuse applications

The use of reclaimed water for landscape irrigation is an important element in the water resources plans for communities in the Phoenix and Tucson metropolitan areas. The cities of Phoenix, Tucson, Mesa, Tempe, Scottsdale, Chandler, Gilbert, Goodyear and Glendale either have constructed or have developed plans to construct wastewater reclamation facilities to supply reclaimed water for landscape irrigation and artificial lakes.

In Phoenix, the Tatum Ranch and Foothills developments have completed construction of reclamation facilities to supply reclaimed water to fill artificial lakes and to irrigate large turf areas, such as golf courses. The initial Foothills reclamation facility was completed in 1989 with a capacity of 670 acre-feet per year [0.6 mgd]. The Tatum Ranch reclamation facility will produce 900 acre-feet per year [0.8 mgd]. The City of Phoenix plans to develop two more water reclamation plants to supply reclaimed water for landscape irrigation of areas of the city north of the Central Arizona Project canal by 2005.

The City of Tucson and Pima County have adopted policies requiring the use of reclaimed water for irrigation of new turf areas. Tucson actively supports the conversion of turf areas that currently are irrigated with potable water to irrigation with reclaimed water. Tucson has an extensive reclaimed water distribution system which delivers water for landscape irrigation throughout the Tucson metropolitan area. In 1990, Tucson's reclaimed water distribution system consisted of an 8.2 mgd treatment plant and over 70 miles of pipeline.

Tucson is planning an expansion of its reclaimed water distribution system with the goal of serving all of the major turf areas in the Tucson metropolitan area with reclaimed water. The City of Tucson projects that most parks and golf courses in the metropolitan area will have access to reclaimed water by 1995. In 1990, the City of Tucson delivered approximately 4,900 acre-feet of reclaimed water to its customers, mainly for irrigation of golf courses and parks. The use of reclaimed water for turf irrigation in the Tucson metropolitan area is expected to increase to over 15,000 acre-feet by the year 2000. The Tucson Reuse Assessment estimates that a total of 18,515 acre-feet of reclaimed water could be used to irrigate approximately 3,378 acres within the Tucson metropolitan area.

Mesa, Tempe, Chandler, Gilber and Scottsdale all plan to use reclaimed water within their city limits. In 1988, the Town of Gilbert delivered approximately 1,200 acre-feet of reclaimed water to a city park and a recreation center for landscape irrigation and artificial lakes. In 1988, the Ocotillo Water Reclamation Plant in Chandler delivered approximately 2,400 acre-feet of reclaimed water for turf irrigation and artificial lakes. In Scottsdale, reclaimed water is used for irrigation of golf courses and for artificial lakes at the Gainey Ranch development. In Glendale, the Arrowhead Ranch water reclamation facility delivers reclaimed water for landscape irrigation. The City of Tempe has recently completed construction of the Kyrene Water Reclamation Plant which will supply reclaimed water for landscape irrigation and golf course irrigation.

The City of Mesa requires by city ordinance that all new turf areas that are over ten acres be irrigated with reclaimed water. Mesa's

water resources plan calls for the development of a water reclamation system with four water reclamation plants that will reuse all of the wastewater produced within the city limits. The first of these water reclamation plants at Turner Ranch (1 mgd) is operating. The final reclamation facility is scheduled for completion by 2001. The City of Mesa is exploring indirect reuse options which incorporate ground water recharge or the underground storage and recovery of reclaimed water.

2. **Existing reclaimed water quality criteria**

The existing rules recognize landscape irrigation as an allowable reuse of reclaimed water. The existing rules distinguish between open access landscape irrigation and restricted access landscape areas irrigation. A higher level of reclaimed water quality is required for open access irrigation.

Under the existing rules, "open access" means that access to the reuse site by the general public is "uncontrolled" [See R18-9-701.8 in Appendix 1]. "Restricted access" means that access to the reuse site by the general public is "controlled" [See R18-9-701.12 in Appendix 1]. Unfortunately, there are no definitions for "controlled" and "uncontrolled" access in the existing reuse rules.

For open access landscape irrigation, the existing rules prescribe a fecal coliform criterion of 25 cfu/100 ml [5-sample geometric mean] and a single sample maximum concentration of 75 cfu/100 ml. There is an enteric virus criterion of 125 enteric units per 40 liters and reclaimed water quality criteria for various parasites However, reuse permittees are not required to monitor for enteric viruses or parasites.

For restricted access landscape irrigation, the existing rules prescribe a fecal coliform of 200 cfu/100 ml [5-sample geometric mean] and a single sample maximum concentration of 1000 cfu/100 ml. No enteric virus or parasite criteria are prescribed for restricted access landscape irrigation with reclaimed water.

Under the existing rules, golf courses that are separated by a fence or barrier that is four feet high are considered to be restricted access areas [See R18-9-703.C.3 in Appendix 1]. The existing rules also state that golf courses that are adjacent to adult-only residential areas are considered to be restricted access areas.

3. **Proposed criteria for landscape irrigation**

In general, public health and aesthetic considerations necessitate a high level of treatment for reclaimed water that is used for landscape irrigation. Reclaimed water must be microbiologically safe because of the potential for ingestion of reclaimed water or inhalation of reclaimed water aerosols. Suspended solids must be

low to prevent the clogging of sprinkler heads and nozzles in the irrigation system. Finally, grease, oil and odors should be removed to preserve the aesthetics of the irrigated area.

ADEQ proposes to retain the distinction between open access and restricted access landscape irrigation and to require separate reclaimed water quality criteria for each.

ADEQ proposes that Class A reclaimed water be required for open access landscape irrigation of parks, playgrounds, schoolyards, green belts and common areas. A high level of reclaimed water quality is appropriate for these areas because they are designed specifically for recreational use or they are located in or near residential areas. The likelihood of direct human contact with reclaimed water, accidental ingestion of reclaimed water or human exposure to reclaimed water aerosols in such areas is high. Children or susceptible adults may be exposed directly to reclaimed water in such urban settings. A pathogen-free reclaimed water should be required to reduce the risk of disease transmission to near zero.

ADEQ proposes that Class B reclaimed water be required for restricted access landscape irrigation. A lower level of reclaimed water quality is acceptable provided public access to the reuse site can be restricted when it is irrigated and there is an adequate buffer zone around the reuse site.

ADEQ proposes to require Class A reclaimed water for the irrigation of golf courses with residential areas that are adjacent to fairways and greens. Golf courses that are adjacent to residential areas should not be considered restricted access areas because of the possibility of wind drift of reclaimed water aerosols from spray irrigation sites. It is difficult, if not impossible, to prevent reclaimed water aerosols from reaching adjacent residential areas. Where reclaimed water aerosols cannot be confined to the reuse site, Class A reclaimed water should be required. This requirement will protect susceptible adults and children who may be exposed to reclaimed water aerosols. Also, there is a high potential for direct human exposure to reclaimed water in residential settings. Even when irrigation with reclaimed water takes place at night when public access to a golf course is restricted, persons who live in adjacent residential areas may be exposed to reclaimed water because of unauthorized entry onto the golf course.

ADEQ proposes to require Class B reclaimed water for golf courses that are fenced and which are separated from residential areas by an adequate buffer zone of 500 feet or more. Class B reclaimed water also is suitable for landscape irrigation in areas that are fenced and where public access to the reuse site during times of irrigation is restricted. [e.g., highway medians and landscapes, cemeteries].

ADEQ Proposal: Require Class A reclaimed water for open access landscape irrigation. Require Class B reclaimed water for restricted access landscape irrigation.

4. Salinity control for landscape irrigation

The long-term use of reclaimed water for landscape irrigation may affect soil salinity and the growth of landscape plants. Research conducted by A.R. Hayes, F. Mancino and I.L. Pepper on the irrigation of turfgrass with secondary sewage effluent indicates that the higher salt content in effluent produces a "small but significant increase in soil salinity" [See A.R. Hayes, et. al. "Irrigation of Turfgrass with Secondary Sewage Effluent, Soil and Leachate Water Quality," Agron. J., 82: 939-943 (1990). The initial results of the research cited above indicate that, while soil salinity increases with reclaimed water irrigation, it does not adversely affect bermuda grass growth. The authors also found that irrigation of turfgrass with reclaimed water produces soil sodium levels that are significantly higher than the levels found in soils that are irrigated with potable water. However, the elevated sodium values were found not to adversely affect the growth of bermuda grass.

The same general principles that were discussed in the context of salinity control for agricultural irrigation also apply to landscape irrigation. The principal difference is that landscape plants may be more salt-tolerant than food crops. In general, the tolerance of turf grasses to total dissolved solids in irrigation water is high [1600 to 2200 mg/L]. Certain common grasses, such as tall fescue, perennial ryegrass and Bermuda grass are tolerant of even higher salinities.

For example, the recommended salinity values in the Tucson Reuse Assessment for landscape irrigation are in the 1500 to 2000 mg/L range for the landscape plants typically grown in the Tucson area [See Tucson Reuse Assessment, Table 3-5, Comparison of Projected Effluent Quality With Recommended Limits for Irrigation, on p. 3-7]. The Tucson Reuse Assessment states that a survey of potential users of reclaimed water for landscape irrigation in the Tucson area indicates that their ornamental plantings are generally salt tolerant. At a salinity of 2000 mg/L, only sensitive ornamentals are appreciably affected. The authors of the Tucson Reuse Assessment state that sensitive ornamental plants can tolerate salinities of 1,100 to 2000 mg/L without appreciable adverse effects. The authors conclude that with adequate leaching of salts, salinities of up to 1,500 mg/l are acceptable for general landscape irrigation and that salinities of up to 2,000 mg/L may be acceptable for irrigation of Bermuda grass turf. ADEQ does not believe TDS regulation is necessary because of the high salinity tolerances of landscape plants and the typically low to moderate concentration of TDS in reclaimed water.

ADEQ Proposal: ADEQ proposes not to regulate TDS concentrations in reclaimed water that is used for landscape irrigation.

5. Nitrates

The use of reclaimed water for landscape irrigation may result in the nitrate contamination of ground water. Total nitrogen that is not taken up by landscape plants may leach to ground water as nitrate.

For example, the increase in nitrate concentrations in ground water downgradient from landscaped areas in the Tucson area to be irrigated with reclaimed water was estimated in the Tucson Reuse Assessment. Increases in nitrate concentrations in ground water in the Tucson area due to the use of reclaimed water for landscape irrigation are estimated to vary from 1 mg/l to over 18 mg/l. In some areas, the estimated nitrate increase in combination with background levels of nitrates in ground water are expected to exceed the National Primary Drinking Water MCL of 10 mg/l. The authors of the Tucson Reuse Assessment conclude that a 50% reduction of total nitrogen concentrations in reclaimed water is necessary to avoid significant ground water quality impacts in the Tucson metropolitan area.

Several alternatives to reduce total nitrogen concentrations in reclaimed water were considered in the Tucson Reuse Assessment. These include:

1. Nitrogen removal at the source wastewater treatment plants.
2. Blending of reclaimed water with ground water or CAP water.
3. Nitrogen removal by land treatment (i.e., land application and nitrification/denitrification in the vadose zone).
4. Best management practices (BMPS) at the reuse site (e.g., removal of grass clippings at landscape irrigation sites).

The recommended options in the Tucson Reuse Assessment for reducing total nitrogen loading were nitrogen removal through land treatment and reuse site BMPs. ADEQ favors reliance on BADCT requirements which require nitrogen removal at the source wastewater treatment plants. Land treatment and BMPs at reuse sites may provide additional nitrogen removal or allow the discharge of reclaimed water with higher total nitrogen concentrations.

ADEQ Proposal: Rely on nitrogen removal at source wastewater treatment plants to regulate total nitrogen concentrations in reclaimed water. Require that total nitrogen concentrations in reclaimed water be less than 10 mg/L, unless it can be shown that a higher concentration of total nitrogen can be discharged by the source wastewater treatment plant and the nitrogen will be utilized by landscape plants at reuse sites.

E. Recreational and landscape impoundments

Reclaimed water may be used for filling landscape ponds, golf course water features and artificial lakes where swimming and boating take place. In some locations in Arizona, fishing is allowed in impoundments of reclaimed water.

Factors which should be considered in establishing water quality criteria for reclaimed water for recreational or landscape impoundments include: 1) assuring adequate microbiological quality; 2) prevention of excessive algae growth and eutrophication; 3) assuring adequate clarity; 4) prevention of objectional color, odor, oil, grease, scum and surfactants which foam; and 5) control of excessive acidity or alkalinity.

Impoundments of reclaimed water fall into two general categories: landscape impoundments and recreational impoundments. A landscape impoundment is an impoundment that is used for aesthetic enjoyment only and which is not intended for recreational purposes. A recreational impoundment is one where full body contact recreation or non-body contact recreational activities take place. There are two types of recreational impoundments. The first type of recreational impoundment is one where recreational activities are restricted to partial body contact activities only [e.g. fishing or boating]. The second type of recreational impoundment is one where full body contact recreation is permitted [e.g., swimming or water-skiing]. This second type is often referred to as an unrestricted recreational impoundment.

As a general rule, the reclaimed water quality criteria for recreational impoundments are more stringent than the criteria for landscape impoundments because of the greater degree of human contact. The reclaimed water quality requirements for unrestricted recreational impoundments are more stringent than the requirements for restricted recreational impoundments.

There are several other states that have rules governing the use of reclaimed water for unrestricted recreational impoundments. These include include California, Colorado, Nevada and Oregon. Nevada requires secondary treatment and disinfection as a minimum level of treatment. California, Colorado and Oregon require secondary treatment + coagulation + filtration + disinfection. California, Colorado and Oregon require that the median total coliform concentration for reclaimed water in unrestricted recreational impoundments not exceed 2.2 cfu/100 ml with no single sample to exceed 23 cfu/100 ml. Nevada requires that the median fecal coliform concentration not exceed 2.2 cfu/100 ml with no single sample to exceed 23 cfu.100 ml.

Arizona currently does not have rules which prescribe required treatment processes. Arizona has less stringent fecal coliform criteria for unrestricted recreational impoundments than its sister

states with similar regulations. However, Arizona is the only state with stringent enteric virus and parasite criteria for reclaimed water that is used in unrestricted impoundment [See next section].

California, Colorado, Nevada, Oregon and Texas have rules governing restricted recreational impoundments. All of them require secondary treatment and disinfection. Median total or fecal coliform criteria for reclaimed water in restricted recreational impoundments range from 2.2 cfu/100 ml [California, Oregon, Colorado and Nevada] to 75 cfu/100 ml [Texas]. Again, Arizona has significantly less stringent reclaimed water quality criteria for restricted recreational impoundments [See next section].

1. Arizona's existing reclaimed water quality criteria

The existing reuse rules prescribe fecal coliform criteria for impoundments where full body contact and incidental human contact take place. The maximum concentration of fecal coliform for an impoundment where full body contact may take place is 200 cfu/ 100 ml (5-sample geometric mean). The single sample maximum concentration of fecal coliform bacteria is 800 cfu/100 ml. The existing rules also prescribe a stringent virus standard for full body contact (1 enteric unit/40 liters) and a "none detectable" standard for Entamoeba histolytica, Giardia lamblia and Ascaris lumbricoides.

For incidental human contact, the fecal coliform criteria are 1000 cfu/100 ml (5-sample geometric mean) and a single sample maximum concentration of 4000 cfu/100 ml. The virus standard for incidental human contact is less stringent (125 enteric units per 40 liters). There are no Entamoeba histolytica or Giardia lamblia criteria for impoundments where incidental human contact takes place.

2. California reclamation criteria for impoundments

ADEQ considered the adoption of the California reclamation criteria for impoundments. California's reclamation criteria specify different treatment trains for impoundments based upon the expected degree of body contact. California recognizes three types of impoundments in its reclamation criteria: landscape, restricted and non-restricted recreational impoundments.

The California reclamation criteria require secondary treatment and disinfection for reclaimed water that is reused in landscape impoundments. Landscape impoundments are defined as impoundments which are used for aesthetic enjoyment only or which otherwise serve a function not intended to include public contact. The California reclamation criteria require the use of a secondary effluent which meets a total coliform concentration of 23 cfu/100 ml. This level of treatment is acceptable for landscape

impoundments because of the negligible degree of human exposure to the reclaimed water.

The California reclamation criteria distinguish between restricted and non-restricted recreational impoundments. A restricted recreational impoundment is one where recreation is limited to fishing, boating and other non-body contact recreational activities. California requires secondary treatment and disinfection of reclaimed water to a total coliform level of 2.2 cfu/100 ml in restricted recreational impoundments. A higher level of disinfection of reclaimed water is required because of the increased degree of human contact with the reclaimed water.

Non-restricted recreational impoundments are defined as impoundments of reclaimed water where there are no limitations imposed on body contact water sport activities [i.e, swimming and water skiing are allowed]. The California reclamation criteria require secondary treatment followed by coagulation, filtration and disinfection to a total coliform level of 2.2 cfu/100 ml for reclaimed water in non-restricted recreational impoundments. The reclaimed water that is used in nonrestricted recreational impoundments is treated to a level that assures complete pathogen removal. This level of treatment is required because of the possibility of ingestion of reclaimed water associated with full body contact recreation.

3. Proposed reclaimed water quality criteria for Arizona

ADEQ proposes to retain recreational and landscape impoundments as allowable reuses of reclaimed water.

For landscape impoundments where no recreational activity is intended, ADEQ proposes to require the use of Class B reclaimed water. That is, wastewater that has received secondary treatment + filtration + disinfection to 23 cfu/100 ml total coliforms [5-sample geometric mean] may be used in a landscape impoundment. No single sample may exceed 240 cfu/100 ml total coliforms.

For recreational impoundments where swimming is allowed, ADEQ proposes to require Class A reclaimed water. That is, reclaimed water that has received secondary treatment + coagulation + filtration + disinfection to 2.2 cfu/100 ml total coliform [5-sample geometric mean]. No single sample may exceed 23 cfu/100 ml.

For recreational impoundments where only partial body contact recreational activities take place [e.g., boating], ADEQ proposes to require Class B reclaimed water. That is, reclaimed water that has received secondary treatment + filtration + disinfection.
ADEQ believes that recreation in and around impoundments of reclaimed water should be limited to partial body contact activities (e.g., fishing and boating) and non-contact recreational activities only. However, ADEQ recognizes that full body contact

recreation may occur incidentally or accidentally. ADEQ believes that Class B reclaimed water provides a reasonable margin of safety.

ADEQ Proposal: Require Class A reclaimed water for unrestricted recreational impoundments. Require Class B reclaimed water for restricted recreational impoundments and landscape impoundments.

4. **Nutrients control in impoundments**

The removal of nutrients in reclaimed water may be necessary to control algae growth in impoundments. Without nutrient control, there is a high potential for algae blooms and eutrophication of reclaimed water impoundments.

ADEQ considered several regulatory approaches to provide adequate nutrient control. First, ADEQ could prescribe numeric, reclaimed water quality criteria for total nitrogen and total phosphorus to control nutrients and prevent eutrophication. Second, ADEQ could require nitrogen removal or phosphorus removal at source wastewater treatment plants before reclaimed water can be used in a recreational or landscape impoundment. Third, ADEQ could prescribe narrative standards which require that impoundments of reclaimed water be free of nuisance algae growth. Fourth, ADEQ could require that best management practices be implemented to control nuisance growth of algae in impoundments [e.g., use of chemical controls or mechanical harvesting].

ADEQ will not prescribe numeric reclaimed water quality criteria for total nitrogen or total phosphorus. The adoption of numeric criteria is inconsistent with the unit treatment-based approach being proposed by ADEQ. ADEQ will require nitrogen removal at source wastewater treatment plants to less than 10 mg/L total nitrogen. Nitrogen removal may help to mitigate eutrophication of impoundments.

ADEQ recognizes that control of total phosphorus is necessary to prevent nutrient loading of reclaimed water impoundments. However, ADEQ also recognizes that advanced wastewater treatment is required to remove phosphorus from wastewater. ADEQ will not require phosphorus removal at source wastewater treatment plants because the high cost of phosphorus removal would effectively preclude the reuse of reclaimed water for recreational and landscape impoundments.

ADEQ proposes to establish a narrative nutrients standard as a general permit condition for the APP general permits for reclaimed water impoundments. This general permit condition will require that impoundments be kept free of excessive or nuisance algae growth. This general permit condition will provide the regulatory basis for ADEQ enforcement action to correct situations where impoundments of reclaimed water create nuisance conditions.

ADEQ Proposal: Require nitrogen removal at source wastewater treatment plants to help mitigate eutrophication problems in impoundments. Do not require phosphorus removal because a phosphorus removal requirement would effectively preclude the reuse of reclaimed water for impoundments. Prescribe a general permit condition for impoundments which prohibits excessive or nuisance algae growth.

5. **Turbidity requirements for impoundments**

The appearance and clarity of reclaimed wastewater in recreational and landscape impoundments are important for reasons of safety, aesthetic appeal and recreational enjoyment.

The existing reuse rules prescribe turbidity requirements for impoundments. Currently, there is a 1 NTU requirement for reclaimed water that is reused in impoundments where full body contact recreation takes place. There is a 5 NTU requirement for reclaimed water that is reused in impoundments where incidental human contact takes place.

ADEQ proposes to require Class A reclaimed water for unrestricted recreational impoundments. This will change the current turbidity requirement for recreational impoundments to 2 NTU. As noted earlier in this paper, compliance with a 2 NTU requirement is technically feasible and will produce an adequately clarified wastewater that is suitable for use in recreational impoundments. This requirement means that the source wastewater treatment plant will be required to supply reclaimed water to the distribution system that meets the 2 NTU requirement. It does not mean that turbidity in an impoundment must be <u>maintained</u> at or below 2 NTU. ADEQ will not propose turbidity requirements for landscape impoundments.

ADEQ proposes to require Class B reclaimed water restricted recreational impoundments and landscape impoundments. The turbidity requirement for Class B reclaimed water is 5 NTUs. This is equivalent to the current turbidity requirements for restricted recreational impoundments.

ADEQ Proposal: For unrestricted recreational impoundments, require that wastewater treatment plants provide Class A reclaimed water that complies with a 2 NTU requirement at the point of entry into the reclaimed water distribution system. For restricted recreational impoundments and landscape impoundments, retain the current 5 NTU requirement.

6. **Impoundment design requirements**

ADEQ will propose that impoundments containing reclaimed wastewater be designed and constructed to prevent discharges to ground water. In general, this means that ADEQ will propose that reclaimed water

impoundments meet BADCT requirements for post-treatment effluent storage ponds.

The BADCT guidance document for municipal and domestic wastewater treatment plants describes a hierarchy of liner systems for impoundments [See Appendix 5]. ADEQ will rely on this hierarchy to establish appropriate liner requirements for impoundments of reclaimed water.

The BADCT guidance document states that clay liners are acceptable for impoundments, depending upon site-specific criteria. An acceptable standard for clay liners is a minimum compacted thickness of 18 inches, compacted to 95% of maximum density with a permeability rate of 1×10^{-7} centimeters per second. In general, ADEQ believes that clay liners should be acceptable for recreational and landscape impoundments of reclaimed water. ADEQ proposes to develop general permit conditions for impoundments of reclaimed water which will prescribe liner requirements.

ADEQ Proposal: Require clay liners for recreational or landscape impoundments of reclaimed water.

7. **Fish consumption**

Some impoundments of reclaimed water are stocked with fish as part of the Arizona Game & Fish Department urban fishing program. ADEQ proposes to require that Class A reclaimed water be used for recreational impoundments where fishing is allowed.

In general, ADEQ believes that the application of secondary treatment, coagulation and filtration technologies will result in a reclaimed water that complies with the numeric criteria that are prescribed to protect the fish consumption designated use in the Water Quality Standards for Navigable Waters rules [Title 18, Chapter 11, Article 1]. The use of Class A reclaimed water will protect the health of persons who consume fish taken from reclaimed water impoundments.

ADEQ Proposal: Require Class A reclaimed water in recreational impoundments where fishing is allowed.

8. **Public notification**

Warning signs should be posted at recreational and landscape impoundments which inform the public that reclaimed water is being used. The warning signs should state that swimming is prohibited and should warn persons to avoid contact with the reclaimed water. Warning signs should be posted at all logical points of entry to the impoundment.

F. Toilet flushing

The first operational wastewater reclamation plant and dual distribution system in the United States to provide reclaimed water for toilet flushing commenced operation in May, 1926 to serve Grand Canyon Village. The original wastewater treatment plant at Grand Canyon consisted of an activated sludge treatment plant with subsequent treatment of the effluent by rapid sand filtration and chlorine disinfection. Reclaimed water was used for toilet flushing in the El Tovar Hotel in Grand Canyon Village. The original reclamation plant and dual distribution system continued to operate from 1926 into the 1960's. In 1972, an expanded wastewater treatment plant was constructed at the Grand Canyon. The 1972 wastewater treatment plant was expanded to 750,000 gpd and upgraded to provide tertiary treatment of wastewater. Reclaimed water from the upgraded wastewater treatment plant still goes into the dual distribution system which continues to serve Grand Canyon Village and private enterprises in Tusayan.

Another significant use of reclaimed water for toilet flushing is in California. The Michelson Water Reclamation Plant in Irvine, California provides advanced wastewater treatment [secondary treatment + chemical coagulation + filtration + disinfection] to produce an reclaimed water having a total coliform concentration of less than 2.2 cfu/100 ml. The Irvine Ranch Water District distributes the reclaimed water through an extensive dual distribution system. Six high rise buildings with dual plumbing systems currently use reclaimed water for flushing toilets and priming floor drain traps.

These "real world" examples demonstrate that reclaimed water may be used safely for toilet flushing. The quality of reclaimed water that is reused for toilet flushing is an important consideration. Reclaimed water that is used for toilet flushing must not discolor vitreous china fixtures, corrode piping or create offensive odors in homes or commercial establishments. For aesthetic reasons, the color of reclaimed water should not be noticeably different from potable water that is typically used for toilet flushing.

The Grand Canyon experience demonstrates that Class B reclaimed water meets these reclaimed water quality requirements. ADEQ proposes to allow the reuse of reclaimed water for toilet flushing and to require the use of Class B reclaimed water.

ADEQ will also propose dual plumbing system requirements in revised Sewage System rules. In general, dual plumbing system requirements should include the following:

1. All reclaimed water piping should be copper piping installed in accordance with the requirements of the Uniform Plumbing Code.
2. All reclaimed water piping should be wrapped with purple

warning tape and imprinted with appropriate warnings.

3. Design plans and specifications for dual plumbing systems should be submitted to ADEQ or a local county health department for technical review.
4. Warning signs in English and Spanish should be installed in valve access panels. Warning signs should notify maintenance personnel that the equipment handles reclaimed water and that appropriate safety precautions should be taken. Signs should be installed in bathrooms to indicate to users of the facility that reclaimed water is used for toilet flushing.
5. An interior separation should be installed inside walls to ensure that reclaimed water and potable water pipes are shielded from each other and to prevent cross connections.

INDUSTRIAL REUSE

1. Current industrial reuse applications

The potential for industrial and commerical reuse of reclaimed wastewater is significant. Reclaimed wastewater may be used for cooling water, boiler feed water, materials washing and transport and for industrial process water. Of these applications, the use of reclaimed wastewater as cooling water is the most important reuse application, accounting for approximately 99% of the total volume of reclaimed water used for industrial reuse water.

For example, one of the largest industrial users of reclaimed water in Arizona is the Palo Verde Nuclear Generating Station [Palo Verde]. Reclaimed water from the 91st Avenue and Tolleson wastewater treatment plants is conveyed by pipeline to an advanced wastewater treatment plant at the Palo Verde site. In 1988, Palo Verde used 46,400 acre-feet of reclaimed water for cooling water for three reactors. Additional on-site wastewater treatment of the reclaimed water is necessary to prevent corrosion, scaling and biological growth in the Palo Verde cooling system.

2. Existing reuse criteria

The existing reuse rules state that each industrial reuse will be considered on an individual basis to determine applicable quality criteria [See R18-9-703.C.8(b) in Appendix 1]. The existing rules recognize that the variety of industrial reuse applications makes it impractical to establish reclaimed water quality criteria governing all industrial reuse.

The existing rules provide two general guidelines for establishing appropriate criteria. In establishing specific criteria, ADEQ shall consider: 1) the degree of potential contact with the reclaimed water by the general public; and 2) the degree of potential contamination of the products or byproducts being produced or handled in the industrial process. The existing rules allow the use of "secondary treated reclaimed wastewater" for use in industrial cooling processes [See R18-9-703.C.8(c)].

3. Proposed reuse criteria for industrial reuse

In general, ADEQ proposes to continue the current approach and evaluate industrial reuse on a case-by-case basis. In general, Class C reclaimed water may be used as source water for industrial reuse applications. However, for most industrial reuse applications, additional treatment will be required at the reuse site.

a. Cooling water

Cooling water systems can be broadly classified as "once-through"

systems or recirculating systems. Once-through systems use reclaimed wastewater for one cooling cycle before it is discharged. Poor quality water is commonly used in once-through systems with minimal treatment. Minimal treatment may include coarse screening and shock chlorination. Once-through cooling systems generally use large volumes of water. Reclaimed water may be used to meet part of the total demand for cooling water in such systems.

Water quality factors of concern in the use of reclaimed wastewater for once-through cooling are (1) the potential for accumulation of deposits from suspended matter in the reclaimed wastewater, and (2) the possibility of biological activity producing slime growths in the cooling system. The temperature of the reclaimed wastewater is also an important consideration. Higher temperatures of reclaimed water may require installation of greater cooling capacity in the system.

Treatment requirements for once-through cooling will vary on a case-by-case basis. In general, secondary effluent can be used although in some cases, reclaimed wastewater may need to be filtered to control total suspended solids. The proposed Class C reclaimed water should be of adequate quality for once-through cooling systems.

Recirculating cooling systems recirculate the same cooling water many times by employing cooling towers or spray ponds to cool the water after each heat-exchange cycle. To prevent the unacceptable build-up of contaminants in the cooling water because of evaporation, a portion of the recirculating water is removed during each cycle and replaced with higher quality water. The process of removing recirculating cooling water is called "blowdown." To replace the cooling water lost in blowdown, the recirculating cooling system requires make-up water. Because the contaminants in the make-up water are concentrated many times during recirculation through the cooling cycle, the make-up water must be of high quality.

If reclaimed wastewater is used for make-up water, it must be of sufficiently high quality so that it does not form scale on heat-exchange surfaces, foam excessively, corrode metal in the cooling system or supply nutrients or organics which will promote biological growth in the cooling system. The reclaimed wastewater also must be of adequate microbiological quality to protect workers from pathogens in wastewater aerosols from the cooling towers or spray ponds.

In general, Class C reclaimed water may be used as <u>source</u> water for recirculating cooling systems. However, additional on-site wastewater treatment will be required before the reclaimed water is introduced into a recirculating cooling system. Additional treatment may include ammonia removal, lime treatment, alum

treatment, chemical precipitation, pH adjustment, filtration, disinfection, ion exchange and reverse osmosis.

b. **Boiler feed water**

The use of reclaimed water for boiler feed water is not cost-effective because of the very high reclaimed water quality requirements. Reclaimed water must undergo extensive treatment before it can be used as boiler feed water. Reclaimed water quality requirements for boiler feed water are dependent upon the pressure at which the boiler is operated. The higher the boiler pressure, the higher the quality of reclaimed water that is required. Very high pressure boilers require make-up water of distilled water quality.

In general, reclaimed water that is used as boiler feed water must be treated to remove hardness. The hardness of boiler feed make up water must be reduced to near zero. Silica and aluminum in reclaimed water are undesirable because they form a hard scale on heat exchanger surfaces. High concentrations of potassium and sodium may cause excessive foaming in the boiler. Additional on-site wastewater treatment to remove these constituents is necessary. Typically, reclaimed water must undergo lime treatment (including flocculation, sedimentation and recarbonation) followed by multimedia filtration, carbon adsorption and nitrogen removal before it can be used as boiler feed water. Class C reclaimed water may be used as source water for boilers, but additional on-site wastewater treatment will be required.

c. **Process water**

The acceptability of reclaimed water for industrial process water is dependent upon the specific industrial reuse application. Relatively low quality effluent may be acceptable for some industrial applications (e.g., concrete mixing) while exceptionally high quality reclaimed water may be needed for other industrial applications (e.g., electronic circuit board washing). The feasibility of using reclaimed water must be evaluated on a case-by-case basis.

d. **Materials washing and sieving**

Reclaimed water may be used by the sand and gravel industry for washing and sieving aggregates. Reclaimed water quality requirements for this type of processing are generally low. Class C reclaimed water is suitable for this purpose provided appropriate worker protection provisions are taken.

e. **Construction applications**

Reclaimed water may be used for construction purposes including: soil compaction during grading operations, dust control and

consolidation and compaction of backfill in reclaimed water, sanitary sewer, storm drain, gas and electric pipeline trenches. Reclaimed water should not be used for consolidation and compaction of backfill in potable water pipeline trenches. In general, Class C reclaimed water is suitable for these construction applications.

f. **Concrete and cement mixing**

Reclaimed water may be suitable for concrete and cement mixing. In general, reclaimed water may be used as mixing water in concrete and cement without harmful effects. However, certain pollutants in reclaimed water may be of concern because they can affect the strength and durability of concrete. Of particular concern is the presence of chlorides in mixing water because of its corrosive effect on steel reinforcement bars. It is recommended that chloride concentrations in reclaimed water be kept below 360 mg/L [as chloride ion] and that sulfate concentrations be kept below 600 mg/L. Also, alkali metal salts in reclaimed water may contribute to alkali-aggregate reactions if reactive aggregates are used [See A. Lieuwen, Effluent Use in Phoenix and Tucson Metropolitan Areas, p. 19]. With these restrictions in mind, it appears that Class C reclaimed water may be used as mixing water for concrete and cement mixing.

g. **Mineral processing**

The use of reclaimed water for mineral processing has been considered by Arizona mines. Research conducted on the technical and economic feasibility of using reclaimed water in the mining industry indicates that the use of secondary effluent may be used for mineral processing. However, the use of secondary effluent reduces mineral recovery rates. These reductions may be mitigated through blending or additional treatment. Class C reclaimed water may be suitable for use as source water for the mining industry if additional on-site wastewater treatment is provided.

DIRECT POTABLE REUSE

Direct potable reuse means the use of reclaimed water for drinking water in a closed loop system. In direct potable reuse, wastewater is treated to very high levels and then reintroduced into the potable water supply system. At the present time, no direct potable reuse systems are in operation in the United States.

One of the most well-known potable reuse demonstration projects in the United States is located in Denver, Colorado. The Denver Potable Reuse Demonstration Plant is a 1 mgd treatment plant which produces reclaimed water for testing and analysis using alternative treatment processes. The product water from the plant is suitable for direct use as drinking water. The plant can treat secondary effluent using chemical coagulation, recarbonation, multimedia filtration, clinoptilolite ion exchange, two-stage carbon adsorption, ultrafiltration or reverse osmosis, air stripping, ozonation and chlorine dioxide disinfection. Tests of reclaimed water quality show that the reclaimed water produced by the plant is comparable to other surface and ground water sources of drinking water for the city of Denver. The Denver reclamation plant demonstrates that it is technologically feasible to treat wastewater so that it is suitable for direct potable use.

Arizona's existing reuse rules prohibit the direct potable reuse of reclaimed wastewater [See A.A.C. R18-9-702.M in Appendix 1]. Despite the demonstrated success of the Denver Potable Reuse Demonstration Plant, ADEQ proposes to retain the prohibition against direct potable reuse for the following reasons. First, even though the water quality results from the Denver demonstration plant are impressive, ADEQ believes that additional research needs to be done on the human health effects of using reclaimed water as drinking water in closed loop systems. Second, the public is not ready to accept direct potable reuse. Third, it is not clear what level of treatment reliability is necessary to prevent treatment failure in a closed loop system. Fourth, direct potable reuse is not practiced anywhere in the world. Finally, direct potable reuse is unnecessary. ADEQ believes that potable water supplies should be conserved for drinking water purposes and that the reuse of reclaimed water should focus on non-potable applications. The nonpotable reuse of reclaimed water can be a substitute for the use of potable water for nonpotable uses. The reuse of reclaimed water for nonpotable uses conserves potable water and can significantly augment the potable water supply.

ADEQ Proposal: The Department proposes to retain the current prohibition against direct potable reuse.

ENVIRONMENTAL REUSE

Constructed Wetlands

Arizona's wetlands are vitally important resources. Natural wetlands provide many worthwhile functions, including flood control, wildlife and waterfowl habitat, aquifer recharge and water quality enhancement. Unfortunately, Arizona has lost much of its natural wetlands habitat. The demand for water by agriculture, mining, industry and the cities has resulted in extensive hydrological modification of the Arizona environment. Wetlands and riparian areas have disappeared as ground water pumping has drained the water from underlying aquifers and rivers and streams have been impounded and diverted. It is estimated that 90 to 95 percent of Arizona's natural riparian areas and wetlands have been lost.

The use of reclaimed water in constructed wetlands can replace some of Arizona's lost natural wetlands habitat. Constructed wetlands can be created through the reuse of reclaimed water, resulting in a net gain in wetland acreage and functions.

There are several locations in northern Arizona that are using reclaimed water in constructed wetlands. Secondarily treated effluent has been used in constucted wetlands in northern Arizona since 1979. The cities of Show Low, Pintetop-Lakeside and Springerville discharge effluent to constructed wetlands at Pintail Lake, Jacques Marsh, and Springerville Marsh. Also, the community of Kachina Village near Flagstaff discharges reclaimed water to approximately 90 acres of constructed wetlands. Other constructed wetlands projects in Arizona include the Kingman Hilltop WWTP, Tusayan WWTP and the Holbrook WWTP.

These constructed wetlands are win/win propositions. When properly designed, constructed wetlands provide cost-effective wastewater treatment, particularly for communities in rural areas. The natural treatment functions of constructed wetlands can enhance the water quality of reclaimed water. Constructed wetlands function as nutrient sinks and buffering zones. Constructed wetlands systems can significantly reduce biological oxygen demand, suspended solids, nitrogen. Metals, trace organics and pathogens are also removed. At the same time, constructed wetlands provide important environmental benefits [e.g, habitat creation]. ADEQ supports the reuse of reclaimed water in constructed wetlands and encourages communities to consider their use to provide cost-effective, environmentally sound, water pollution control.

In general, ADEQ proposes to regulate constructed wetlands under the APP program. A constructed wetlands will require an individual APP. Where the constructed wetlands is an integral part of a wastewater treatment plant, it will be treated as a unit treatment process. The APP for the source wastewater treatment plant and the

constructed wetland will be consolidated in such cases. Where the constructed wetland is primarily for off-site disposal of effluent or for creation or enhancement of wildlife habitat, a separate APP for the constructed wetland may be required. An NPDES permit would be required for a flow-through constructed wetland that discharges to a navigable water.

Constructed wetlands that are designed as infiltration wetlands will require individual APPs. However, certain types of constructed wetlands may be amenable to a general APP. For example, it may be possible to develop a general permit for constructed wetlands with lined subsurface flow systems. Subsurface flow wetlands are essentially horizontal trickling filters with the added component of emergent plants within the filter media. These types of constructed wetlands typically consist of an inclined trench or bed with an underlying clay or synthetic liner. The bed contains the filter media which supports the growth of emergent vegetation. The filter media may be rock, sand or soils. In general, they operate by introduction of wastewater at one end of the wetland. As the wastewater passes through the wetland, it is treated by filtration, sorption and precipitation processes. The physical-chemical and biochemical processes that take place in the wetland are substantially equivalent to the processes that take place in conventional treatment systems, including denitrification.

Also, a general permit may be developed for free water surface systems with synthetic or clay liners. A free water wetlands typically consists of basins or channels, with a clay or synthetic liners to prevent infiltration to ground water, soil or another suitable medium to support emergent vegetation and water at a relatively shallow depth.

The existing rules recognize the creation of artificial wetlands as an allowable reuse of reclaimed water [See R18-9-703.C.7]. The existing reuse standards also apply to the addition of reclaimed water to an existing, man-made wetlands marsh. This type of reuse is to be distinguished from the point source discharge of reclaimed water to a natural wetlands. The latter discharge is considered a discharge to a navigable water that is regulated under the NPDES permit program.

There are existing reclaimed water quality criteria for fecal coliform, pH, dissolved oxygen, temperature and trace substances. The allowable fecal coliform limits are 1000 cfu/100 ml (30-day geometric mean) and 4000 cfu/100 ml (single sample maximum). The pH of the reclaimed water must be between 6.5 to 8.6 standard units and the maximum pH change per day is 0.5 standard units. The dissolved oxygen concentration in the reclaimed water in the wetlands marsh must be maintained at 6.0 mg/l or higher. The temperature of the reclaimed water "shall not interfere with aquatic life and wildlife." Finally, reclaimed water that is

discharged to a wetlands marsh must meet surface water quality standards for trace substances.

In general, ADEQ proposes to require Class C reclaimed water for introduction into constructed wetlands that are lined. Infiltration wetlands must be evaluated on a case-by-case basis. Constructed wetlands will require an individual APP. However, general permits may be developed for certain types of lined constructed wetlands. Finally, ADEQ proposes to revise the BADCT guidance document for domestic and municipal wastewater treatment plants to specifically address the design of constructed wetlands.

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ARTICLE 2. RESERVED

ARTICLE 3. RESERVED

ARTICLE 4. RESERVED

ARTICLE 5. RESERVED

ARTICLE 6. RESERVED

ARTICLE 7. REGULATIONS FOR THE REUSE OF WASTEWATER

R18-9-701. Definitions

Definitions given in R18-9-802, R9-20-203, and applicable state statutes will apply to those words and phrases when used in this Article. In addition, the following apply:

1. "Reuse of reclaimed wastewater" means the use of reclaimed wastewater transported from the point of treatment to the point of use without an intervening discharge to the surface waters of the state for which water quality standards have been established.
2. "Effluent" means wastewater that has completed its passage through a wastewater treatment plant.
3. "Gray water" means wastewater that originates from clothes washers, dishwashers, bathtubs, showers, and sinks, except kitchen sinks and toilets.
4. "Industrial wastewater" means all wastes that enter a collection, treatment or disposal system from an industrial process.
5. "Irrigation" means the application of water or wastewater or both for growing agricultural crops or for landscaping purposes.
6. "NPDES permit" means a permit issued by the United States Environmental Protection Agency for discharge to the waters of the United States as required by the Clean Water Act, as amended.
7. "On-site wastewater treatment plant" encompasses all of the processes, devices, structures, and earthworks used for treating wastewater for disposal and reuse other than septic tanks with a hydraulic capacity less than two thousand (2,000) gallons per day that possess a N.S.F. Class I rating.
8. "Open access" means that access to the reuse site by the general public is uncontrolled.
9. "Partially treated wastewater" means wastewater which has received a minimum of primary treatment but does not meet the allowable limits contained in R18-9-703 for release to a reuse, or for discharge into the waters of the United States.
10. "Primary treatment" is a treatment process which accomplishes removal of sewage solids by physical means so that the effluent contains no more than 1.0 milligram of settleable solids per liter of wastewater.
11. "Reclaimed wastewater" is effluent which meets the standards for the specific reuses contained in R18-9-703.
12. "Restricted access" means that the access to the reuse site by the general public is controlled.
13. "Reuse" means the use of reclaimed wastewaters.
14. "Reuse site" means that area where reclaimed wastewater is applied to and/or impounded upon.
15. "Secondary treatment" is a treatment process that produces treated wastewater containing no more than 30 milligrams per liter of five-day biochemical oxygen demand, 30 milligrams per liter of suspended solids, a pH between the limits of 6.0 to 9.0, and a fecal coliform standard based on the uses of the wastewater. Aerobic stabilization ponds shall be considered as providing secondary treatment if the effluent contains no more than 30 milligrams per liter of five-day biochemical oxygen demand, 90 milligrams per liter of suspended solids for pond systems treating less than or equal to two million gallons per day, plus the same pH and fecal coliform standards given above. Pond systems with a design capacity of greater than two million gallons per day must meet the 30 milligram per liter standard for suspended solids.
16. "Wastewater" means sanitary wastes of human origin, sewage, gray water, and industrial wastes that contain sanitary wastes or are used in the production or processing of any crop or substance which may be used as human or animal food.
17. "Wastewater reclamation system" means the wastewater treatment plant and the entire reuse and distribution system for the reclaimed wastewater.
18. "Wastewater treatment plant" encompasses all of the processes, devices, structures, and earth-works which are used for treating wastewater for disposal and reuse but does not include septic tanks, wastewater treatment plants serving single family residences, industrial unit processes, or industrial impoundments for process waters within the industrial property.

Historical Note

Former Section R9-20-401 repealed, new Section R9-20-401 adopted effective May 24, 1985 (Supp. 85-3). Former Section R9-20-401 renumbered without change as Section R18-9-701 (Supp. 87-3).

R18-9-702. General requirements for reuse of wastewater

A. The application of reclaimed wastewater shall be consistent with the goals and policies of the Council.

B. Irrigation with untreated wastewater is prohibited.

C. No wastewater treatment plant owner shall release reclaimed wastewater for reuse without a permit issued by the Department.

D. Food crops which may be consumed raw by humans that are irrigated with reclaimed wastewater shall be considered adulterated foods in accordance with A.R.S. § 36-904(A)(5), unless the reclaimed wastewater conforms with the limits and conditions of R18-9-703. The production, sale or delivery of such adulterated food crops is prohibited and the Director may detain, remove, or destroy such adulterated food crops pursuant to A.R.S. § 36-910.

E. A reuser may accept reclaimed wastewater and provide additional treatment for a more restrictive reuse. Under such conditions, the plant providing the additional treatment is subject to the same requirements as other wastewater treatment plants and will be permitted separately.

F. When no means of reuse, discharge, or disposal of reclaimed wastewater are available other than surface irrigation, a minimum of five days storage shall be provided to prevent the necessity of irrigation when the soil is saturated or during a period when the reclaimed wastewater does not meet the minimum water quality standards for the specific reuse. The irrigation site shall be designed to contain the runoff from a 10-year, 24-hour precipitation event unless the reclaimed wastewater meets the standards and conditions of a valid NPDES permit for discharge into waters of the United States. These provisions shall not apply to agricultural irrigation return flows, and runoff from highway landscaping or golf courses when the Department determines that such a flow does not present a danger to the health of the public.

G. Discharges of effluent into waters of the United States require a NPDES permit and are not regulated by this Article.

H. In determining allowable uses of reclaimed wastewater, the Department will consider the effects of blending secondary effluent with waters of higher quality or the effects of additional treatment prior to reuse if requested by the applicant. In cases where blending or additional treatment of secondary effluent is provided, the user shall submit to the Department, as a minimum, a plan of operation, a description of any additional treatment process, blending volumes, and an estimation of final quality at the point of reuse.

I. The wastewater treatment plant owner or the reclaimed wastewater owner shall be responsible and liable for meeting the conditions of the wastewater reuse permit. The treatment plant owner will not be liable for misapplication of reclaimed wastewater by reusers. To identify the responsibilities of the wastewater treatment plant owner and the reclaimed wastewater owner there shall be a legally enforceable contract which sets forth as a minimum:
   1. The quality and maximum quantity of wastewater to be released for reuse by the wastewater treatment plant.
   2. The specific reuse(s) for which the reclaimed wastewater will be used by the reuser.
   3. The method of disposal of any reclaimed wastewater left over from the reuse activity by the reuser.
   4. The responsibility for compliance with additional requirements for specific reuses as contained in R18-9-703(C) by the reuser.

J. In those cases where the reclaimed wastewater is owned by someone other than the wastewater treatment plant owner, the reclaimed wastewater owner may apply for the reuse permit pursuant to R18-9-705(A) and perform any of the other functions required by this Article so long as the reclaimed wastewater owner, in a form acceptable to the Director, commits to perform any or all of the duties required in this Article and/or produces a legally enforceable contract with the wastewater treatment plant owner which commits performance to any or all of the duties required in this Article. The intent of this policy is that the wastewater treatment plant owner and the reclaimed wastewater owner, either together or separately, agree to commit to all of the requirements of this Article, as shown in a legally enforceable contract.

K. In cases where someone other than the wastewater treatment plant owner makes an actual reuse of the reclaimed wastewater, each succession of ownership shall be governed by a legally enforceable contract, filed with the Department, which notifies the succeeding reclaimed wastewater owner of the requirements of this Article and which requires the succeeding owner to so contract with any additional succeeding reclaimed wastewater owners.

L. Nothing in this Article is intended to exempt disposal of reclaimed wastewater from the requirements of A.A.C. Title 9, Chapter 20, Article 2.

M. The use of reclaimed wastewater for direct human consumption is prohibited.

Historical Note

Former Section R9-20-402 repealed, new Section R9-20-402 adopted effective May 24, 1985 (Supp. 85-3). Former Section R9-20-402 renumbered without change as Section R18-9-702 (Supp. 87-3).

R18-9-703. Specific standards and permit monitoring requirements for the reuse of wastewater

A. Numerical parameter limits pertaining to specific reuse categories are contained in Table I of this Article and A.A.C. Title 18, Chapter 11, Article 2. Concentrations of trace substances, organic chemicals, toxic substances, and radiochemicals in waters used for agricultural irrigation, livestock watering, and recreation must meet the allowable limits contained in the State surface water quality standards, A.A.C. Title 18, Chapter 11, Article 2. Permit monitoring requirements for specific reuses are given in Table II of this Article. The regulations in this part apply to effluent flow at a point in the wastewater reclamation system just prior to release for reuse.

B. Permittees are not required to monitor routinely for enteric viruses, entamoeba histolytica, giardia lamblia, ascaris lumbricoides, common large tapeworm, trace substances, organic chemicals, toxic substances, or radiochemicals for which no sampling frequency is specified. However, should the Department find or have reason to believe such contaminants are present in excess of the allowable limits given in Table I of this Article and A.A.C. Title 18, Chapter 11, Article 2, corrective action including monitoring will be required to eliminate or reduce the contaminants to meet these limits.

TABLE I -- ALLOWABLE PERMIT LIMITS FOR SPECIFIC REUSES

PARAMETER	A ORCHARDS	B FIBER, SEED & FORAGE	C PASTURES	D LIVESTOCK WATERING	E PROCESSED FOOD	F LANDSCAPED AREAS RESTRICTED ACCESS	G LANDSCAPED AREAS OPEN ACCESS	H FOOD CONSUMED RAW	I INCIDENTAL HUMAN CONTACT	J FULL BODY CONTACT
pH	4.5-9	4.5-9	4.5-9	6.5-9	4.5-9	4.5-9	4.5-9	4.5-9	6.5-9	6.5-9
FECAL COLIFORM (CFU/100 ml)[a]										
geometric mean (5 sample minimum)	1000	1000	1000	1000	1000	200	25	2.2	1000	200
single sample 4000 not to exceed	4000	4000	4000	2500	1000	75	25	4000	800	
TURBIDITY (NTU)[b]	–	–	–	–	–	–	5	1	5	1
ENTERIC VIRUS[c]	–	–	–	–	–	–	125 per 40 liters	1 per 40 liters	125 per 40 liters	1 per 40 liters
ENTAMOEBA HISTOLYTICA	–	–	–	–	–	–	– detectable	none	– detectable	none
GIARDIA LAMBLIA	–	–	–	–	–	–	– detectable	none	– detectable	none
ASCARIS LUMBRICOIDES	–	–	–	–	–	–	none detectable	none detectable	none detectable	none detectable
COMMON LARGE TAPEWORM	–	– detectable	none detectable	none	–	–	–	–	–	–

Notes: a. CFU = colony forming units
b. NTU = nephlometric turbidity units
c. expressed as PFU, plaque forming units; MPN, most probable numbers; or immunofluorescent foci per liter
d. "None detectable" means no pathogenic microorganisms observed during examination

TABLE II -- MINIMUM PERMIT MONITORING REQUIREMENTS FOR SPECIFIC REUSES

PARAMETER	Frequency									
	A ORCHARDS	B FIBER, SEED & FORAGE	C PASTURES	D LIVESTOCK WATERING	E PROCESSED FOOD	F LANDSCAPED AREAS RESTRICTED ACCESS	G LANDSCAPED AREAS OPEN ACCESS	H FOOD CONSUMED RAW	I INCIDENTAL HUMAN CONTACT	J FULL BODY CONTACT
pH	1/month	1/month	1/month	1/month	1/month	1/month	1/month	1/month	1/month	1/month
FECAL COLIFORM	1/month	1/month	1/month	1/month	1/month	1/week	1/day	1/day	1/week	1/day
TURBIDITY	–	–	–	–	–	–	continuous	continuous	continuous	continuous

C. Additional requirements for specific uses.

1. Irrigation of orchard crops and crops not subject to rotation (Table I, Column A). Irrigation shall be by a method which minimizes contact of the reclaimed wastewater with the fruit or foliage.
2. Irrigation of pastures (Table I, Column C). Pastures must be maintained to prevent incidental ponding or standing water except where local farming conditions and the use of accepted irrigation delivery systems and cropping patterns are such that, as an unavoidable consequence of such conditions, systems, and patterns, there will be standing water.
3. Irrigation of landscaped areas, cemeteries, highway medians, golf courses, and other areas where public access is restricted (Table I, Column F). Golf courses in residential areas which are separated by a fence or barrier of at least four feet in height will be included in this category. Golf courses contiguous with a residential area primarily restricted to adults or which strictly enforce nonaccess for anyone other than players will be included in this category.
   a. Spray irrigation of fairways shall be limited to such times of the day as to reasonably preclude direct contact of the spray with golfers.
   b. Irrigation spray shall not reach any privately-owned premises or public drinking fountains.
   c. Hose bibbs discharging reclaimed wastewater shall be posted with signs reading "Reclaimed Water, Do Not Drink", or similar warnings, or be secured to prevent access by the public.
   d. Signs reading "Irrigation with reclaimed wastewater" or similar warning shall be prominently displayed on the premises. Score cards shall include the same warning.
   e. Irrigation pipe shall be color coded, buried with colored tape, or otherwise suitably marked to indicate non-potable water.
4. Irrigation of landscaped areas including playgrounds, lawns, parks, golf courses not covered by Paragraph (3) above, and other areas where public access is not restricted (Table I, Column G).
   a. Hose bibbs discharging reclaimed wastewater shall be secured to prevent any use by the public.
   b. Irrigation pipe shall be color coded, buried with colored tape, or otherwise suitably marked to indicate nonpotable water.
   c. These areas shall be irrigated only at such time as to minimize contact with the public and be reasonably dry and free from standing water during normal usage periods.
   d. Signs reading "Irrigated with reclaimed wastewater" or similar warnings shall be prominently displayed on the premises.
5. On-site wastewater treatment plants.
   a. For surface irrigation, on-site wastewater treatment plant effluent must meet the allowable limits listed in Table III of this Article. Surface irrigation sites shall be designed to contain a 10-year, 24-hour rainfall event. On-site wastewater treatment plants which use reclaimed wastewater within common areas or discharge to areas off the reuse site are subject to quality, monitoring, management, and operation requirements which pertain to all other wastewater treatment plants.
   b. This Section does not apply to on-site wastewater treatment plants that dispose effluent through the following means:
      i. Conventional leach trenches designed in accordance with Department engineering bulletins.
      ii. Mound disposal systems.
      iii. Evapotranspiration beds designed in accordance with Department engineering bulletins.
6. Gray water from single and multi-family residences may be used for surface irrigation under the following conditions:
   a. The design and construction of the system are approved by the Department in accordance with A.A.C. Title 18, Chapter 9, Article 8. Design guidelines and information on suitable plantings and irrigation methods are available from the Department.
   b. Such irrigation sites shall be designed to contain a 10-year, 24-hour rainfall event.
   c. The gray water must meet the allowable limits for surface irrigation in Table III.

TABLE III

ALLOWABLE LIMITS AND MONITORING REQUIREMENTS FOR SURFACE IRRIGATION WITH ON-SITE WASTEWATER TREATMENT PLANT EFFLUENT AND GRAY WATER

Parameters	Allowable Limits	Samples Required
Fecal Coliform (CFU/100 ml)		
geometric mean	25	Series of 5 in one
calendar month; 1 series per year minimum		
single sample not to exceed	75	
Chlorine Residual, mg/l	2.0	1/month minimum

7. Wetlands marsh.
   a. Formation of a wetlands marsh is an allowable reuse of reclaimed wastewater under conditions and design criteria outlined in Engineering Bulletin No. 11, available from the Department.
   b. Table IV of this Article contains minimum effluent standards and monitoring requirements for formation of a wetlands marsh or addition of reclaimed wastewater to an existing man-made wetlands marsh.

TABLE IV

ALLOWABLE LIMITS AND MONITORING REQUIREMENTS FOR RECLAIMED WASTEWATER RELEASED TO WETLANDS MARSHES

Parameters	Allowable Limits	Samples Required
FECAL COLIFORM (CFU/100 ml, 30-day period)		
FLOWS LESS THAN 1 MILLION GALLONS PER DAY		
geometric mean	1000	5/month
single sample not to exceed	4000	
FLOWS 1 MILLION GALLONS PER DAY OR ABOVE		
geometric mean	1000	10/month
single sample not to exceed	4000	
pH, units	6.5-8.6	1/week
pH CHANGE, units/day, maximum change per day in receiving waters	0.5	
DISSOLVED OXYGEN, receiving waters shall not be lowered beyond this limit (mg/l)	6	2/week
TEMPERATURE	shall not interfere with aquatic life and wildlife	2/week
TRACE SUBSTANCES	per A.A.C. Title 18, Chapter 11, Article 2 "aquatic and wildlife"	

8. Industrial reuse.
   a. All wastewater reclamation systems that contain industrial wastewater will be subject to these rules, if they either:
      i. Totally or partially consist of or originated as a sanitary waste of human origin; or,
      ii. Are used for the production and processing of any crops or substance which may be used as human or animal food.
   b. Reuse of reclaimed wastewater for industrial purposes is exempt from these rules under the following circumstances:
      i. The industrial wastewater did not originally contain sanitary wastes of human origin; or,
      ii. The wastewater is not used for the production or processing of any crop or substance which may be used as human or animal food.
   c. If not exempt, each industrial reuse will be considered on an individual basis to determine applicable quality criteria. The variety of industrial reuses is so extensive that establishing specific criteria governing all industrial reuses is not practicable. In fixing such treatment requirements and quality criteria the Department shall give consideration to:
      i. The degree of potential contact with the reclaimed wastewater by the general public.
      ii. The degree of potential contamination of the products or byproducts being produced or handled in the industrial process.
   d. The use of secondary treated reclaimed wastewater for use in industrial cooling processes shall be allowed.

Historical Note

Former Section R9-20-403 repealed, new Section R9-20-403 adopted effective May 24, 1985 (Supp. 85-3). Former Section R9-20-403 renumbered without change as Section R18-9-703 (Supp. 87-3). Editorial change to labels in subsection (c)(8) (Supp. 89-4).

R18-9-704. Irrigation as part of the wastewater treatment process

Irrigation with partially treated wastewater is considered a part of the treatment process and is subject to the same Department controls as other wastewater treatment processes. Such irrigation is allowable only under all of the following conditions:

1. The person having administrative control over the wastewater treatment plant or the reclaimed wastewater owner has direct physical and administrative control over the irrigation site and process.
2. The entire treatment process, including irrigation and harvesting, is under the direct supervision of a wastewater treatment plant operator certified by the Department under A.A.C. Title 18, Chapter 4, Article 1.
3. The irrigation site, cropping, application rates, irrigation practices, harvesting, and a plan of operation shall have been approved by the Department.
4. Land to which partially treated wastewater is applied shall not be used for crops requiring higher quality irrigation water until such land use is approved in writing by the Department.
5. Any discharge of partially treated wastewater from the irrigation site shall be from a designated discharge point or points and shall meet the limits and conditions of NPDES permit or a groundwater permit issued under A.A.C. Title 9, Chapter 20, Article 2.

Historical Note

Former Section R9-20-404 repealed, new Section R9-20-404 adopted effective May 24, 1985 (Supp. 85-3). Former Section R9-20-404 renumbered without change as Section R18-9-704 (Supp. 87-3).

R18-9-705. Permit for reuse of reclaimed wastewater

A. To effectuate R18-9-702(C), above, the following shall apply:
   1. Application for a permit and signatories.
      a. The owner or operator of any wastewater treatment plant or reclaimed wastewater owner who proposes to allow the reclaimed wastewater to be reused for any of the purposes authorized by these rules shall complete, sign and submit to the Director information requested in an application form provided by the Department.
      b. All permit applications shall be signed by either a principal executive officer or ranking elected official.
   2. Time allowed for application submittal. A person proposing a reuse facility shall submit an application not less than 120 days before the date on which the reuse is to commence, unless permission for a lesser period has been granted by the Director.
   3. Reissuance of permit: time allowed for application submittal. A person who expects to continue to release reclaimed wastewater for reuse after expiration of the permit shall apply for reissuance not less than 120 days before the expiration date of the present permit.
   4. Duration of permits and continuation of expiring permits.
      a. All permits shall be issued for fixed terms not to exceed five years. Permits may be modified, transferred, reissued, or revoked by the Director.
      b. The term and conditions of an expired permit are automatically continued under the provisions of A.R.S. § 41-1012(B) pending issuance of a new permit if:
         i. The permitted activity is of a continuing nature.
         ii. The permittee has submitted a timely and sufficient application for a new permit.
         iii. The Department is unable, through no fault of the permittee, to issue a new permit before the expiration date of the previous permit.
   5. Public comment and hearings, public notice regarding permits and permit hearings.
      a. Notices shall be circulated in a manner designed to inform interested persons of a hearing or determination dealing with permit denial or issuance. Notice of draft permit shall allow at least 30 days for public comments and notice of hearing shall be given 30 days before the hearing.
      b. Notice of the formulation of any draft permit and notice of all hearings shall be given by the Department:
         i. By mailing a copy to the applicant, to interested state and county agencies, and to any person on request.
         ii. By any of the following methods:
            (1) By publication of a notice in a daily or weekly newspaper within the area affected by the wastewater reuse activity or discharge; or,
            (2) by posting a copy of the information required at the principal office of the municipality or political subdivision affected by the wastewater reuse activity or discharge, and by posting a copy at the United States Post Office serving those premises.
            (3) In any other manner constituting legal notice under State law.

B. Public notices issued under this Section will contain the following information:
   1. Name and address of the office processing the application or conducting the hearing.
   2. Name and address of the applicant and the wastewater treatment plant owner (if different from the applicant) and a general description of the location of each existing or proposed reuse facility.
   3. Name of person, and an address and telephone number where interested persons may obtain further information, including copies of the draft permit.

C. Transfer of permits. A permit may be transferred to another person by a permittee if:
   1. The permittee notifies the Director of the proposed transfer.
   2. A written agreement containing a specific date for transfer of permit responsibility and coverage between the current and new permittees (including acknowledgment that the existing permittee is liable for violations up to that date, and that the new permittee is liable for violations from that date on) is submitted to the Director.
   3. The Director, within 30 days of receiving a transfer notice, does not notify the current permittee and the new permittee of the intent to modify, revoke and reissue, or terminate the permit and to require that a new application be filed rather than agreeing to the transfer of the permit.

D. Permit compliance. To assure compliance with permit terms and conditions, the permittee shall monitor:
   1. The amount, concentration, or other measurement for each contaminant from Table II of this Article and A.A.C. Title 18, Chapter 11, Article 2 specified in the permit.
   2. The volume of reclaimed wastewater released for reuse.
   3. Other parameters specifically required in the permit.
   4. The Director will specify the following monitoring requirements in the permit:
      a. Requirements concerning proper installation, use and maintenance of monitoring equipment or methods (including biological monitoring methods where appropriate).
      b. Monitoring frequency, type and intervals sufficient to yield continuing data representative of the volume of reclaimed wastewater flow and the quantity of contaminant discharged.
      c. Test procedures for the analysis of contaminant meeting the requirements of this Section.
   5. Test procedures identified in 40 CFR Part 136 shall be utilized for contaminants or parameters listed in the permit unless an alternative test procedure has been approved by the Director.

E. Recording of monitoring results.
   1. Any permittee required to monitor shall maintain records of all monitoring information and monitoring activities, including:
      a. The date, exact place and time of sampling or measurements;
      b. The person who performed the sampling or measurements;
      c. The date analyses were performed;
      d. The person who performed the analyses;
      e. The analytical techniques or methods used;
      f. The results of such analyses.
   2. All records of monitoring activities and results (including all original strip chart recordings for continuous

monitoring instrumentation and calibration and maintenance records) shall be retained by the permittee for three years. The three-year period shall be extended:

a. Automatically during the course of any unresolved litigation regarding the discharge of contaminants by the permittee;

b. As requested in writing by the Director.

F. Access to records. The manager of the wastewater treatment plant shall allow any and all of the reusers to have access to the records of physical, chemical and biological quality of the reclaimed wastewater.

G. Availability of records. Water quality records of the wastewater facility will be available for public inspection at the Department.

H. Reuses requiring lower quality reclaimed wastewater than that allowed by permit. It is expressly allowed that a reuser of reclaimed wastewater may use the water for any purpose included in these rules which requires a lower quality than that set forth in the permit.

Historical Note

Former Section R9-20-405 repealed, new Section R9-20-405 adopted effective May 24, 1985 (Supp. 85-3). Former Section R9-20-405 renumbered without change as Section R18-9-705 (Supp. 87-3).

R18-9-706. Enforcement and penalties

Any person who releases reclaimed wastewater for reuse without a permit or contrary to provisions of a permit or this Article, falsifies data or information submitted to the Department as a result of the requirements of this Article, or otherwise violates the provisions of this Article, shall be subject to enforcement and penalties pursuant to A.R.S. §§ 49-262 and 49-263 and any other applicable and appropriate provisions of the Arizona Revised Statutes.

Historical Note

Former Section R9-20-406 repealed, new Section R9-20-406 adopted effective May 24, 1985 (Supp. 85-3). Former Section R9-20-406 renumbered without change as Section R18-9-706 (Supp. 87-3). Amended effective December 1, 1988 (Supp. 88-4).

R18-9-707. Severability

If any provision of this Article is finally adjudicated invalid, the remaining provisions of this Article shall not be affected thereby.

Historical Note

Former Section R9-20-407 repealed, new Section R9-30-407 adopted effective May 24, 1985 (Supp. 85-3). Former Section R9-20-407 renumbered without change as Section R18-9-707 (Supp. 87-3).

ARTICLE 8. SEWAGE SYSTEMS

R18-9-801. Legal authority

The rules in this Article are adopted pursuant to the authority granted by A.R.S. § 49-104(B)

Historical Note

Corrected A.R.S. reference (Supp. 77-3). Former Section R9-8-311 renumbered without change as Section R18-9-801 (Supp. 87-3). Amended effective December 1, 1988 (Supp. 88-4).

R18-9-802. Definitions

A. "Approved" or "approval" means approved in writing by the Department.

B. "Department" means the Department of Environmental Quality or a local health department designated by the Department.

C. "Disposal system" means a system for disposing of wastes, either by surface or underground methods, and includes sewerage systems, treatment works, disposal wells, and other systems.

D. "Engineer" means the person or firm which designed the sewage works and conceived, developed, executed, or supervised the preparation of the plan documents.

E. "Individual disposal system" means a device or system for the treatment or disposal of sewage from a single housing unit.

F. "Person" means the state or any agency or institution thereof, any municipality, political subdivision, public or private corporation, individual, partnership, association, or other entity, and includes any officer or governing or managing body of any muncipality, political subdivision, or public or private corporation.

G. "Plan documents" means reports, proposals, preliminary plans, survey and basis of design data, general and detail construction plans, profiles, specifications, and all other information pertaining to sewage works planning.

H. "Pollution" means such contamination, or other alteration of the physical, chemical, or biological properties of any waters of the state, including change in temperature, taste, color, turbidity, or odor of the waters, or such discharge of any liquid, gaseous, solid, radioactive, or other substance into any waters of the state as will or is likely to create a public nuisance or render such waters harmful, detrimental, or injurious to public health, safety, or welfare, or to domestic, agricultural, commercial, industrial, recreational, or other beneficial uses, or to livestock, wild animals, birds, fish or other aquatic life.

I. "Sewage" means wastes from toilets, baths, sinks, lavatories, laundries, and other plumbing fixtures in residences, institutions, public and business buildings, mobile homes, watercraft, and other places of human habitation, employment, or recreation.

J. "Sewerage system" means pipelines or conduits, pumping stations, and force mains, and all other structures, devices, appurtenances, and facilities used for collecting or conducting wastes to an ultimate point for treatment or disposal.

K. "Treatment works" means any plant or other works used for the purpose of treating, stabilizing, or holding wastes.

L. "Wastes" means sewage, industrial wastes, and all other liquid, gaseous, solid, radioactive, or other substance which may pollute or tend to pollute any waters of the State. The term "wastes" does not include agricultural irrigation and drainage waters for which water quality standards shall have been established pursuant to Chapter 11.

M. "Waters of the State" means all waters within the jurisdiction of this state including all streams, perennial or intermittent, lakes, ponds, impounding reservoirs, marshes, watercourses, waterways, wells, springs, irrigation systems, drainage systems, and all other bodies or accumulations of water, surface and underground, natural or artificial, public or private, situated wholly or partly within or bordering upon the state.

N. "Certified Water Quality Management Plan" means a plan prepared by the designated Water Quality Management Planning Agency pursuant to Section 208 of the Federal Water Pollution Control Act (P.L. 92-500) as amended by the Clean Water Act of 1977 (P.L. 95-217), adopted by the Water Quality Control Council, and certified by the Governor.

O. "Designated management agency" means those entities designated in the Certified Water Quality Management Plans to manage sewerage systems and sewage treatment works in respective area.

P. "Facility plan" means the plans, specifications, and estimates for proposed sewerage systems and sewage treatment works

APPENDIX 2

RULE ADOPTION PROCESS

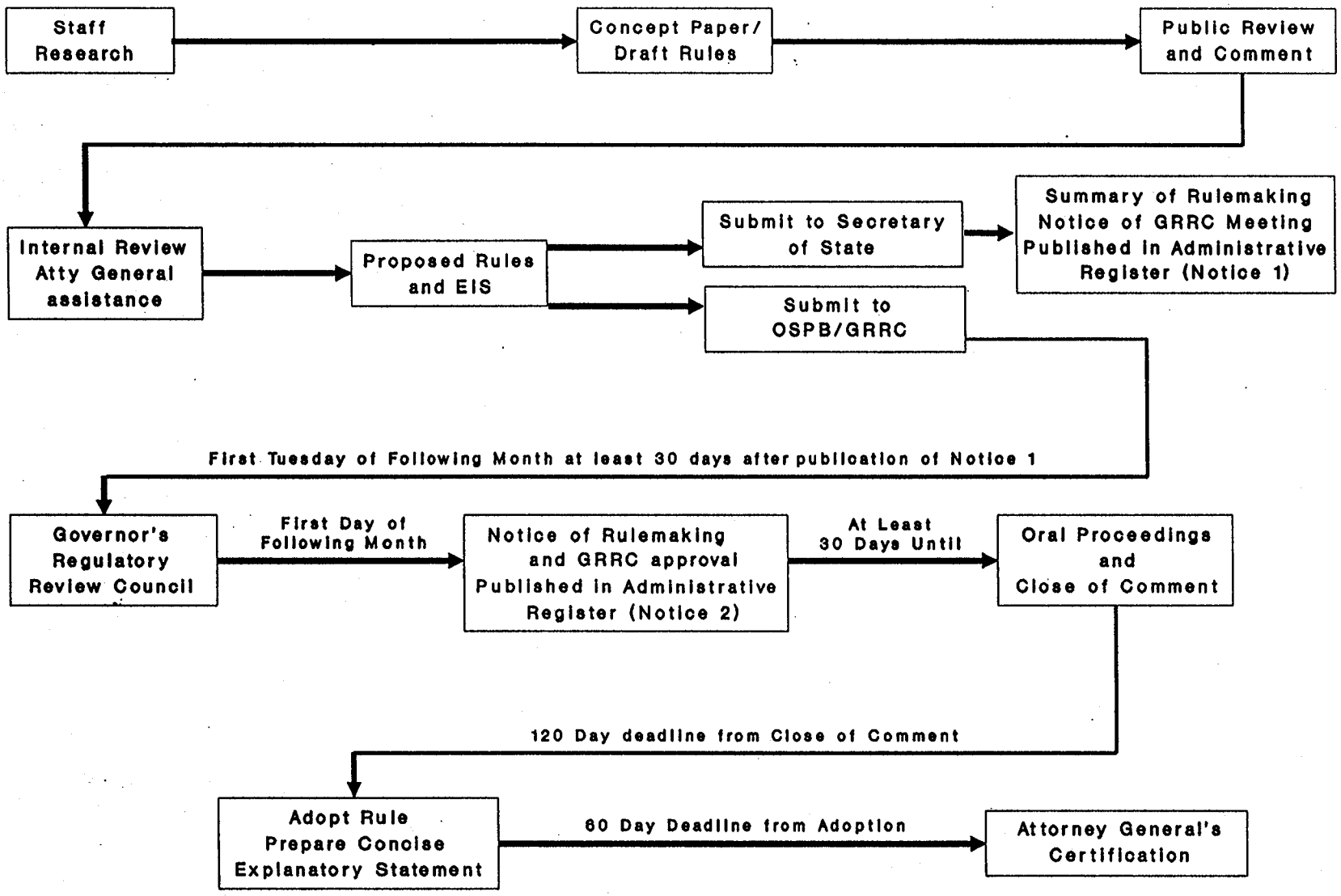

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TABLE 2.3-11
SUMMARY OF CLASS I RELIABILITY REQUIREMENTS

Unit	Class I Requirement
Mechanically-Cleaned Bar Screen	A backup bar screen shall be provided (may be manually cleaned).
Pumps	A backup pump shall be provieded for each set of pumps which performs the same function. Design flow will be maintained with any one pump out of service.
Communication Facilities	If communication is provided, an overflow bypass with bar screen shall be provided.
Primary Sedimentation Basins	There shall be sufficient capacity such that a design flow capacity of 50% of the total capacity will be maintained with the largest unit out of service.
Filters	There shall be a sufficient number of units of a size such that a design capacity of at least 75% of the total flow will be maintained with one unit out of service.
Aeration Basins	At least two basins of equal volume will be provided.
Mechanical Aerator	At least two mechanical aerators shall be provided. Design oxygen transfer will be maintained with one unit out of service.
Chemical Flash Mixer	At least two basins or a backup means of mixing chemicals separate from the basins shall be provided.
Final Sedimentation Basins	There shall be a sufficient number of units of a size such that 75% of the design capacity will be maintained with the largest unit out of service.
Flocculation Basins	At least two basins shall be provided.
Disinfectant Contact Basins	There shall be sufficient number of units of a size such that the capacity of 50% of the total design flow may be treated with the largest unit out of service.

Adapted from "Design Criteria for Mechanical, Electric, and Fluid System and Component Reliability, EPA, 1974.

Source: EPA/U.S. AID Water Reclamation Reuse Guidelines

APPENDIX 4

Table 3.4-1
Recommended Limits for Constituents in Reclaimed Water for Irrigation (Adapted from EPA, 1973)

TRACE HEAVY METALS

Constituent	Long-Term Use (mg/l)	Short-Term Use (mg/l)	Remarks
Aluminum	5.0	20	Can cause nonproductivity in acid soils, but soils at pH 5.5 to 8.0 will precipitate the ion and eliminate toxicity.
Arsenic	0.10	2.0	Toxicity to plants varies widely, ranging from 12 mg/l for Sudan grass to less than 0.05 mg/l for rice.
Beryllium	0.10	0.5	Toxicity to plants varies widely, ranging from 5 mg/l for kale to 0.5 mg/l for bush beans.
Boron	0.75	2.0	Essential to plant growth, with optimum yields for many obtained at a few-tenths mg/l in nutrient solutions. Toxic to many sensitive plants (e.g., citrus) at 1 mg/l. Usually sufficient quantities in reclaimed water to correct soil deficiencies. Most grasses relatively tolerant at 2.0 to 10 mg/l.
Cadmium	0.0	0.05	Toxic to beans, beets, and turnips at concentrations as low as 0.1 mg/l in nutrient solution. Conservative limits recommended.
Chromium	0.1	1.0	Not generally recognized as essential growth element. Conservative limits recommended due to lack of knowledge on toxicity to plants.
Cobalt	0.05	5.0	Toxic to tomato plants a 0.1 mg/l in nutrient solution. Tends to be inactivated by neutral and alkaline soils.
Copper	0.2	5.0	Toxic to a number of plants at 0.1 to 1.0 mg/l in nutrient solution.
Fluoride	1.0	15.0	Inactivated by neutral and alkaline soils.
Iron	5.0	20.0	Not toxic to plants in aerated soils, but can contribute to soil acidification and loss of essential phosphorus and molybdendum.
Lead	5.0	10.0	Can inhibit plant cell growth at very high concentrations.
Lithium	2.5	2.5	Tolerated by most crops at up to 5 mg/l; mobile in soil. Toxic to citrus at low doses - recommended limit is 0.075 mg/l.
Manganese	0.2	10.0	Toxic to a number of crops at a few-tenths to a few mg/l in acid soils.
Molybdenum	0.01	0.05	Nontoxic to plants at normal concentrations in soil and water. Can be toxic to livestock if forage is grown in soils with high levels of available molybdenum.
Nickel	0.2	2.0	Toxic to a number of plants at 0.5 to 1.0 mg/l; reduced toxicity at neutral or alkaline pH.
Selenium	0.02	0.02	Toxic to plants at low concentrations and to livestock if forage is grown in soils with low levels of added selenium.
Tin, Tungsten, and Titanium	–	–	Effectively excluded by plants; specific tolerance levels unknown
Vanadium	0.1	1.0	Toxic to many plants at relatively low concentrations.
Zinc	2.0	10.0	Toxic to many plants at widely varying concentrations; reduced toxicity at increased pH (6 or above) and in fine-textured or organic soils.

OTHER PARAMETERS

Constituent	Recommended Limit	Remarks
pH	4.5-9.0	Most effects of pH on plant growth are indirect (e.g., pH effects on heavy metals' toxicity described above).
TDS	500-2,000 mg/l	Below 500 mg/l, no detrimental effects are usually noticed. Between 500 and 1,000 mg/l, TDS in irrigation water can affect sensitive plants. At 1000 to 2000 mg/l, TDS levels can affect many crops and careful management practices should be followed. Above 2,000 mg/l, water can be used regularly only for tolerant plants on permeable soils.

Source: EPA/U.S. AID Water Reclamation Reuse Guidelines

TABLE II

Hierarchy of Liner Systems

Configurations (Optimal Design Listed First)

1. Double flexible membrane system with primary and secondary leachate collection system.

2. Double flexible membrane system with secondary leachate collection only.

3. Double liner system with primary and secondary leachate collection - upper liner is flexible membrane and lower liner is compacted soil.

4. Double liner system with secondary leachate collection - upper flexible membrane and lower liner is compacted soil.

5. Single liner flexible membrane with primary leachate collection system.

6. Single liner of compacted soil with primary leachate collection.

7. Single liner of bentonite or amended soil with primary leachate collection.

8. Flexible membrane liner without leachate collection.

9. Compacted soil liner without leachate collection.

10. Bentonite liner without leachate collection.

11. Amended soil without leachate collection.

12. Grouted soil or grouted bedrock.

13. Other liner types.

DRAFT FOR REVIEW AND DISCUSSION
APR 21 1992